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LEVEL

REVIEW of REPORTS

on

LAKE ERIE – LAKE ONTARIO

WATERWAY N.Y.

APPENDIX D

ECONOMICS

U.S. ARMY CORPS OF ENGINEERS
BUFFALO DISTRICT

OCTOBER 1973

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The purpose of this review is to examine the conclusions from the environmental, engineering and economic studies of the construction of a water way between Lake Erie and Lake Ontario in the United States. This report will also serve as a basis for further action by Congress.

DD $_{1 JAN 73}^{FORM}$ 1473 EDITION OF 1 NOV 65 IS OBSOLETE

REVIEW OF REPORTS
ON
LAKE ERIE - LAKE ONTARIO WATERWAY

APPENDIX D
ECONOMIC STUDY

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INTRODUCTION

D-1 This appendix discusses existing and prospective traffic between Lake Erie and Lake Ontario for each of seven commodity groups: (1) grain, (2) coal, (3) petroleum, (4) clay, cement, stone, sand, and gravel, (5) iron ore, (6) other bulk, and (7) general cargo. Table D-1 is a detailed definition of commodity groups used in this report.

The traffic studies include a detailed origin-destination study of United States bulk and general cargo and a thorough analysis of Canadian traffic patterns with emphasis on the Lake Erie-Lake Ontario traffic interchange. There have been numerous traffic studies conducted in recent years involving Great Lakes-St. Lawrence Seaway transportation. A complete review of published data has been accomplished as part of the economic studies for the Lake Erie-Lake Ontario Waterway and a bibliography is contained at the end of this appendix. Individual studies are cited when specific reference is made herein.

EXISTING TRAFFIC

D-2 Origin Destination Study. To develop the data base for traffic movements a port-to-port study was made involving all U. S. shipping and receiving ports and 20-commodity groups for traffic utilizing the

TABLE D-1

Definition of Commodity Groups

1. Grain and Farm Produce

    Corn
    Soybeans
    Wheat
    Barley
    Oats
    Rice
    Sorghum Grains
    Flaxseed
    Oilseeds, n.e.c.
    Tobacco, leaf
    Hay and Fodder
    Field crops, n.e.c.
    Fresh fruits
    Coffee
    Cocoa beans
    Miscellaneous farm products

2. Coal

    Coal and lignite

3. Petroleum and Products

    Distillate fuel oil
    Residual fuel oil
    Gasoline
    Crude petroleum
    Jet fuel
    Kerosene
    Lubricating oils and greases
    Asphalt, tar, and pitches
    Asphalt
    Petroleum products, n.e.c.

4. Clay, Cement, Stone, Sand, & Gravel

    Limestone
    Building stone
    Sand, gravel, and crushed rock
    Clay
    Building cement
    Lime
    Cut stone
    Stone products

D-2

Definition of Commodity Groups

5. Iron Ore

Iron ore and concentrates

6. Other Bulk

Bauxite
Manganese ores
Nonferrous metal ores
Pulp
Newsprint paper
Paper and paperboard
Crude rubber
Forest products
Phosphate rock
Natural fertilizer materials
Salt
Sulphur, dry
Nonmetallic minerals
Logs
Pulpwood, logs
Lumber
Veneer and plywood
Coke
Misc. shipments

7. General Cargo

Glass and glass products
Wood manufactures
Iron and steel ingots
Iron and steel bars, rods, angles, shapes, and sections
Iron and steel plates and sheets
Iron and steel pipe and tube
Ferro alloys
Iron and steel products, n.e.c.
Iron and steel scrap
Lead and Zinc including alloys, unmarked
Aluminum and aluminum alloys, unworked
Nonferrous metal scrap
Sodium hydroxide (caustic soda)
Dyes, organic pigment, dying,and tanning materials
Radioactive and associated materials, including wastes
Basic chemicals and chemical products, n.e.c.

7. <u>General Cargo cont'd</u>

Plastic materials
Synthetic rubber
Synthetic fiber
Drugs
Soap, detergents, and cleaning preparations;
    perfumes and cosmetics
Paint, varnishes, lacquers, and enamels
Gum and wood chemicals
Nitrogenous fertilizer and materials
Potassic fertilizer materials
Insecticides, fungicides, pesticides, and disinfectants
Fertilizers and materials, n.e.c.
Miscellaneous chemical products
Fresh fish
Meat
Tallow and lard
Animal by-products, n.e.c.
Dairy products
Dried milk and cream
Prepared or preserved fish and products
Vegetables
Fruits, and fruit and vegetable juices
Wheat flour and semolina
Animal feeds
Grain mill product, n.e.c.
Sugar
Molasses
Alcoholic Beverages
Vegetable oils; margerine and shortening
Miscellaneous food products
Motor vehicles, parts, and equipment
Aircraft and parts
Ships and boats
Miscellaneous transportation equipment
Machinery, except electrical
Electrical equipment, machinery, and supplies
Ordnance and accessories
Tobacco Manufactures
Basic textile products
Textile fibers, n.e.c.
Furniture and fixtures
Printed matter
Rubber and miscellaneous plastic products
Leather and leather products
Glass and glass products
Instruments, photographic and optical goods, watches and clocks
Miscellaneous products and manufacturing apparel and textile products

existing Welland Canal. Each port in the Great Lakes-St. Lawrence
Seaway system was analyzed to determine the existing traffic patterns
and volume of traffic. From this analysis of individual ports, a
system definition was developed to group individual ports into a
workable number to facilitate the development of an origin-destination
traffic matrix. Plate D-1 depicts the system definition developed
for origin-destination traffic studies. The ten-reach system includes:
(1) each of the 5-Great Lakes, (2) the Detroit River-Lake St. Clair
area between Lakes Huron and Erie, (3) West Canada defined as Canadian
ports in the Great Lakes west of the Welland Canal, (4) East Canada
defined as the Canadian ports in Lake Ontario and the St. Lawrence
River, (5) Coastwise which includes the U. S. East and Gulf Coast
areas, and (6) overseas in all directions. Origin-destination tables
are introduced in the individual commodity group discussions below, to
illustrate the 1971 base year Welland Canal traffic involving U. S.
ports, for each of the seven commodity groups and for the composite
total. As shown in Table D-2, the 1971 Welland Canal traffic total was
62.9 million tons of which 43.3 million tons involved U. S. origins and
destinations. The remaining 19.6 million tons involved Canada - Canada
and Canada-Overseas traffic for which detailed origin-destination points
were not available.

D-3 __United States Traffic__. With the opening of the St. Lawrence
Seaway in 1959, overseas and Eastern Canadian markets became accessible
by direct waterborne movements to and from U. S. Great Lakes ports.
As a result traffic through the Welland Canal, linking Lake Erie

PLATE 1

DEFINITION OF REACHES IN
ORIGIN/DESTINATION TRAFFIC STUDY

JANUARY 1967

SCALE OF MILES
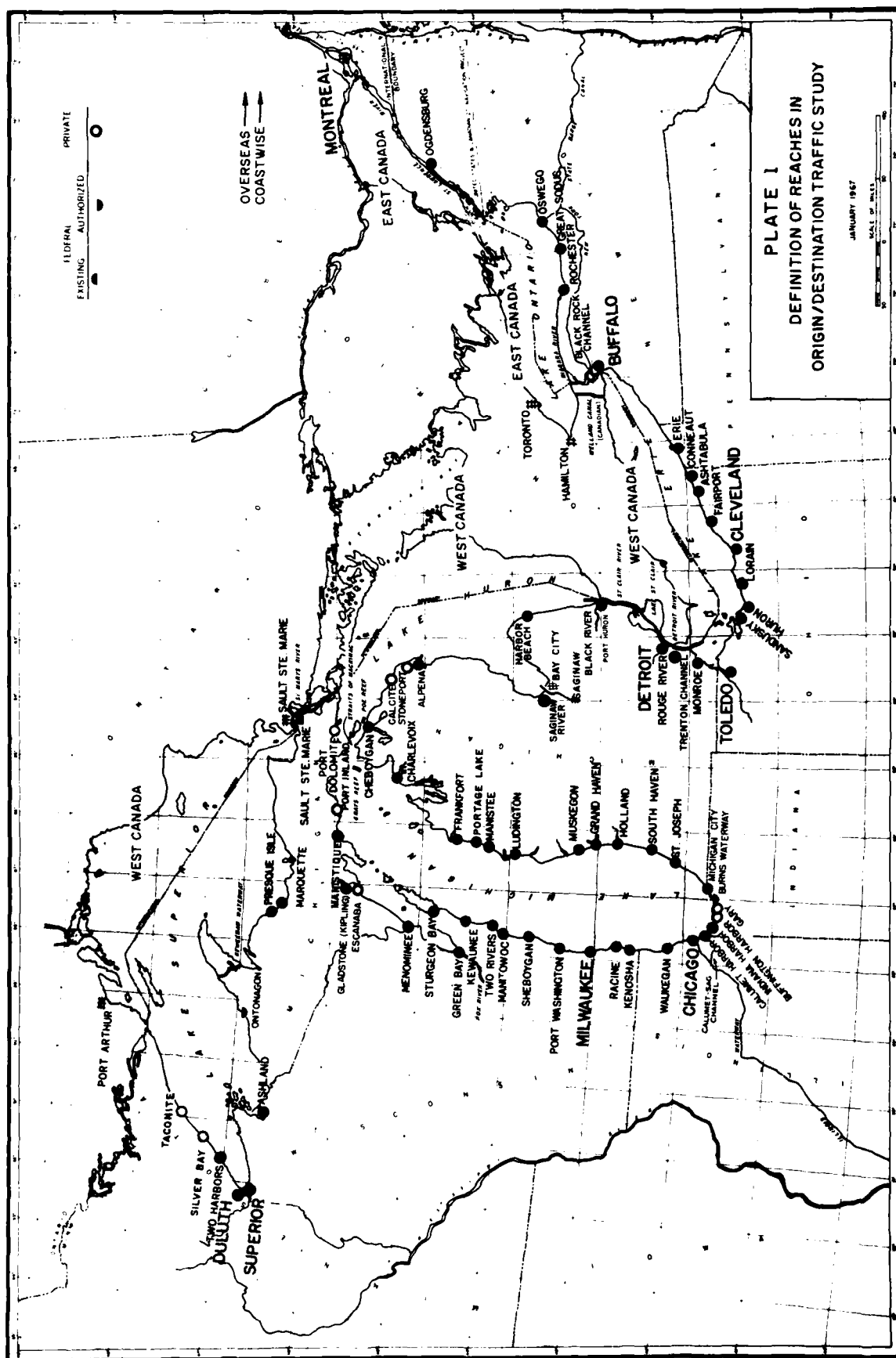
TABLE D-2

Welland Canal Traffic by type and by commodity groups, 1962-1972, Actual

YEAR	ALL TRAFFIC Total	Upbound	Downbound	U.S.-U.S. Up	Down	U.S.-OVERSEAS Up	Down	U.S.-CANADA Up	Down	CANADA-U.S. Up	Down	CANADA-CANADA Up	Down	CAN.-OVERSEAS Up	Down
						TOTAL ALL COMMODITIES									
1962	35,402	10,855	24,547	359	723	1,101	4,992	2	11,770	7,959	27	1,370	6,390	64	645
1963	41,253	13,139	28,114	414	632	1,436	4,047	1	14,355	10,040	9	1,142	8,304	106	767
1964	51,386	18,539	32,847	381	632	1,974	5,606	15	14,944	14,730	29	1,252	10,905	187	731
1965	53,436	19,974	33,462	347	613	3,773	6,206	11	15,715	14,243	58	1,428	9,817	172	1,053
1966	59,269	22,567	36,702	265	719	4,043	6,942	7	15,447	16,422	71	1,658	12,613	172	910
1967	52,809	22,404	30,405	257	742	4,278	5,606	-	14,289	16,263	27	1,485	8,513	121	1,228
1968	58,074	26,181	31,893	300	608	6,366	6,080	21	16,590	17,729	37	1,590	7,837	175	741
1969	53,532	19,378	34,154	268	585	4,776	6,925	-	18,175	12,372	4	1,704	7,854	258	611
1970	62,868	21,142	41,726	217	658	4,530	6,602	-	19,376	14,602	23	1,606	14,045	187	1,022
1971	62,909	21,585	41,324	137	609	6,920	8,864	16	14,748	12,832	24	1,378	15,512	302	1,567
1972	64,095	21,126	42,969	135	531	6,234	9,655	3	15,425	12,788	35	1,686	15,626	280	1,697

SOURCE: The St. Lawrence Seaway Authority and the Saint Lawrence Seaway Development Corporation, Traffic Report of the St. Lawrence Seaway, 1962-1972.

NOTE: Two major sources of data were used for traffic in this report; (1)Traffic Report of the St. Lawrence Seaway, prepared by the St. Lawrence Seaway Authority and the Saint Lawrence Seaway Development Corporation, and (2) Waterborne Commerce of the United States, prepared by the U. S. Army Corps of Engineers. Data differ slightly between the two sources, e.g., base year 1971-total U. S. traffic through the Welland Canal is as follows: Source (1) - 44,150,000 tons and Source (2) - 43,311,000 tons. Both totals will be referenced in this report and used interchangeably according to the source quoted at the time.

D-7

and Lake Ontario increased from 13.8 million tons in 1958 to over

20 million tons in 1959. As shown in Table A-3, steady increases

in traffic occurred during the 1960-1970 decade with a high of

47.7 million tons reached in 1968. Traffic volume has fluctuated

with national and international market conditions of supply and

demand for bulk and general cargo commodities. The dominant move-

ments reflected in United States traffic, utilizing the Welland

Canal, are in the: (1) United States to Canada movement which

accounts for about 30-35 percent of total U. S. Welland Canal

traffic, and (2) Canada to United States traffic which accounts

for an additional 25-30 percent of the total. The United States

to Canada movement is made up largely of coal from Lake Erie

ports to Canadian Lake Ontario power plants and grain to Canadian

ports on Lake Ontario and the St. Lawrence River for domestic

consumption and export transhipment. The Canada to U. S. traffic

is almost exclusively iron ore from Canadian Labrador mines to

steel producing U. S. ports on Lake Erie and Lake Michigan. Over-

seas traffic makes up the remaining 30-40 percent of U. S. traffic

utilizing the Welland Canal. Direct overseas traffic interchange

with U. S. Great Lakes ports has increased sharply in the early

years of the 1970 decade. Downbound exports of grain and upbound

imports of iron and steel are largely responsible for the current

growth in U. S. overseas traffic.

TABLE D-3

Welland Canal Traffic by Type and by Commodity Groups
1958-1960, 1962-1972, Actual

UNITED STATES TRAFFIC

YEAR	U.S. WELLAND CANAL TRAFFIC			U.S.-U.S.		U.S.-OVERSEAS		U.S.-CANADA		CANADA-U.S.	
	Total	Upbound	Downbound	Up	Down	Up	Down	Up	Down	Up	Down
				TOTAL ALL COMMODITIES							
1958	13,793	3,793	10,000	316	1,033	320	344	4	8,592	3,153	31
1959	20,214	8,200	12,014	334	676	1,061	2,830	23	8,477	6,782	31
1960	21,596	7,037	14,559	351	734	852	3,902	35	9,903	5,799	20
1962	26,933	9,421	17,512	359	723	1,101	4,992	2	11,770	7,959	27
1963	30,934	11,891	19,043	414	632	1,436	4,047	1	14,355	10,040	9
1964	38,311	17,100	21,211	381	632	1,974	5,606	15	14,944	14,730	29
1965	40,966	18,374	22,592	347	613	3,773	6,206	11	15,715	14,243	58
1966	43,916	20,737	23,179	265	719	4,043	6,942	7	15,447	16,422	71
1967	41,462	20,798	20,664	257	742	4,278	5,606	–	14,289	16,263	27
1968	47,731	24,416	23,315	300	608	6,366	6,080	21	16,590	17,729	37
1969	43,105	17,416	25,689	268	585	4,776	6,925	–	18,175	12,372	4
1970	46,008	19,349	26,659	217	658	4,530	6,602	–	19,376	14,602	23
1971	44,150	19,905	24,245	137	609	6,920	8,864	16	14,748	12,832	24
1972	44,626	19,160	25,466	135	531	6,234	9,655	3	15,425	12,788	35

CANADIAN TRAFFIC

YEAR	CANADA WELLAND CANAL TRAFFIC			CANADA-CANADA		CANADA-OVERSEAS	
	Total	Upbound	Downbound	Up	Down	Up	Down
			TOTAL ALL COMMODITIES				
1958	7,481	1,213	6,268	1,186	6,155	27	113
1959	7,292	1,396	5,896	1,346	5,339	50	557
1960	7,660	1,349	6,311	1,230	5,474	119	837
1962	8,469	1,434	7,035	1,370	6,390	64	645
1963	10,319	1,248	9,071	1,142	8,304	106	767
1964	13,075	1,439	11,636	1,252	10,905	187	731
1965	12,470	1,600	10,870	1,428	9,817	172	1,053
1966	15,353	1,830	13,523	1,658	12,613	172	910
1967	11,347	1,606	9,741	1,485	8,513	121	1,228
1968	10,343	1,765	8,578	1,590	7,837	175	741
1969	10,427	1,962	8,465	1,704	7,854	258	611
1970	16,860	1,793	15,067	1,606	14,045	187	1,022
1971	18,759	1,680	17,079	1,378	15,512	302	1,567
1972	19,289	1,966	17,323	1,686	15,626	280	1,697

SOURCE: The St. Lawrence Seaway Authority and the Saint Lawrence Seaway
Development Corporation, Traffic Report of the St. Lawrence Seaway,
1958-1972.

D-4 Canadian Traffic. Traffic involving Canada-Canada and
Canada overseas movements accounted for 30 percent of the 64.1
million tons passing the Welland Canal in 1972. Canadian traffic
(i.e., traffic not having an origin or destination at U. S. ports)
has been increasing steadily as a percentage of total Welland Canal
traffic, having accounted for an average of only 22 percent in the
1960-1969 decade compared with the present 30 percent share. As
shown in Table D-3, the major Canadian traffic movement utilizing
the Welland Canal is in the downbound direction, from Western Great
Lakes ports to Lake Ontario and St. Lawrence River ports. The
specific commodities moving from West to East Canada are mainly
agricultural commodities of wheat, barley, oats, and corn. These
and other farm commodities make up 80 percent of the Canadian
traffic. Other commodities are: (1) iron ore, (2) salt, (3) chemi-
cals, (4) fuel oil, and (5) miscellaneous bulk materials. Canadian
traffic involving overseas origins and destinations, at present,
play a relatively small role in the Welland Canal traffic total
(about 3 percent in 1972).

COMMODITY ANALYSIS AND PROJECTIONS OF UNITED STATES LAKE ERIE-LAKE ONTARIO WATERBORNE COMMERCE

D-5 The definition of commodity groups used in this study are shown in Table D-1. The major commodity groups are: (1) grains and farm produce, (2) coal, (3) petroleum and products, (4) clay, cement, stone, sand, and gravel, (5) iron ore, (6) other bulk materials and (7) general cargo. For port-to-port origin-destination traffic studies and transportation rate analyses, a more detailed commodity breakdown was used, as shown in Table D-4. The twenty sub-groups were defined according to homogeneous characteristics of production origin and/or transportation advantage which, together with existing and projected supply and demand variables, provided the basis for commodity projections of future waterborne commerce utilizing the Welland Canal.

D-6   <u>Grain and Farm Produce</u>. The Great Lakes Harbors Study[1] completed in 1967 contained a <u>Grain Traffic Analysis</u>[2] which projected U. S. grain export for the periods 1980 and 2015. The analyses of grain and farm produce for the Lake Erie-Lake Ontario Waterway economic benefit study constitutes a current update of the <u>Grain Traffic Analysis</u>. In addition, Volume II of the recently published commodity studies and projections, <u>U. S. Deepwater Port Study</u>[3], provided an indepth analysis of total U. S. and international grain supply and demand characteristics.

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[1] U. S. Army Corps of Engineers, <u>Great Lakes Harbors Study</u>, Summary <u>Report</u>, 1967.
[2] U. S. Army Corps of Engineers, <u>Grain Traffic Analysis</u>, 1965.
[3] U. S. Army Corps of Engineers, Institute for Water Resources, <u>U. S. Deepwater Port Study</u>, Volume II, 1972.

TABLE D-4

DEFINITION OF COMMODITY GROUPS

Commodity Group	Sub-Group
1. Grain	a. corn b. soybeans c. wheat d. other farm produce
2. Coal	a. coal
3. Petroleum	a. fuel oil b. gasoline c. other petroleum and products
4. Clay, Cement, Stone, Sand, and Gravel	a. clay, cement, stone, sand, and gravel
5. Iron Ore	a. iron ore
6. Other Bulk Materials	a. pulp and paper b. metallic ores (other than iron ore) c. other bulk materials
7. General Cargo	a. iron and steel b. other primary metals c. chemicals d. food e. transportation equipment f. machinery g. other maufactures

As shown in Table D-5, of the 8.6 million tons of U. S.
grain shipments in base year 1971, 5.5 million tons moved overseas
and 3.0 million tons were destined for Canadian ports east of the
Lake Erie-Lake Ontario Waterway. An even distribution of grain
shipments occurred among Lake Superior, Lake Michigan, and Lake Erie
ports with the Duluth-Superior ports on Lake Superior having the
largest individual port area total grain traffic.

Areas importing grain from U. S. Great Lakes ports include the
European Economic Community, other western European countries, the
Mediterranean, Japan, and other Far Eastern countries, and most recently,
the Soviet Union and Mainland China. A continued strong demand is
expected for grain and farm produce in future decades, particularly
in corn and soybeans, the leading world feed grains. With the growing
world population and increased standard of living the demand for meat
is expected to increase, having a corollary effect on the demand for
feed grains. This together with trends toward greater wheat consumption
in the Far East, Middle East, and India impacts heavily on the total
world demand for grain and farm produce. The grain producing states,
tributary to the U. S. Great Lakes,[4] produce over 30 percent of U. S.
wheat, 65 percent of U. S. corn, and 60 percent of U. S. soybeans. Inland
transportation links to U. S. Great Lakes ports provide service from
country elevators to terminal elevators at the primary shipping ports

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[4] North Dakota, South Dakota, Minnesota, Wisconsin, Iowa, Illinois,
Indiana.

TABLE D-5

Origin-Destination of U. S. Lake Erie-Lake Ontario Grain Traffic

YEAR 1971

COMMODITY 1 GRAIN

FROM PORT	TO LK SUP.	LK MICH.	DET.STCL	LK HURON	GREAT LAKES PORTS LK ERIE	LK ONTAR	W CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0	0	0	0	0	41159	0	5050074	0	2366228
LK MICH.	0	0	0	0	0	0	0	722287	0	1716853
DET.STCL	0	0	0	0	0	0	0	361	0	6956
LK HURON	0	0	0	0	0	0	0	98306	0	0
LK ERIE	0	0	0	0	0	0	0	1131232	0	1425124
LK ONTAR	0	0	0	0	0	0	0	0	0	0
W CANADA	0	0	0	0	0	0	0	0	0	0
E CANADA	0	12657	0	0	0	0	0	0	0	0
COASTWIS	0	0	0	0	0	0	0	0	0	0
OVERSEAS	1257	37900	521	8169	0	0	0	0	0	0
TOTALDOWN	1257	40557	521	8169	0	41159	0	3062260	0	5535161
TOTLACROS	3457461	2459140	7317	98306	2556356	0	0	12657	0	37847

TOTAL TONS FOR THIS COMMODITY 1 GRAIN IS 8629084.

of Duluth-Superior, Chicago, and Toledo. Grain exporters in each

of the three major port areas have reported that in recent years

grain exports from U. S. Great Lakes ports would have shown greater

increases if more vessels to move the grain were available.

As shown in Table D- 6 traffic in grain and farm produce

between Lake Erie and Lake Ontario is projected to increase from

8.6 million tons in 1971 to 11.0 million tons in 1980, 13.5 million

tons in 1990, 20.0 million tons in 2015, and 26.0 million tons in

2040.   The level of exports, reflected in the U.S. Great Lakes projections,

is considered to represent only a retention of the existing share of

total U. S. exports, a figure which varies between 15 and 20 percent.

TABLE D- 6

U. S. Great Lakes Grain Exports Via Lake Erie-Lake Ontario Waterway
1960-1971, Actual and 1980, 1990, 2015 and 2040 Projected
(000 Tons)

1960-65 – 6,313
1966-70 – 7,440
1971 – 8,629
1980 – 11,000
1990 – 13,500
2015 – 20,000
2040 – 26,000

D-7 Coal. The movement of coal from U. S. Lake Erie ports

for consumption at Canadian Lake Ontario ports increased from

4.4 million tons in 1958 to highs of 10.8 million tons in 1969

and 10.5 million tons in 1970 (Table D-7). Virtually all of

the waterborne coal traffic,utilizing the present Welland Canal,

is a U. S. to Canada movement,as illustrated by the origin-

destination traffic matrix, Table D-8. The coal originates in

the Ohio River Basin and is delivered to Lake Erie ports of

Toledo, Conneaut, Ashtabula,and Sandusky for waterborne distri-

bution. Major Canadian ports in the distribution pattern are

Port Credit - Toronto, Hamilton, Oshawa,and Picton. The coal is

presently utilized,primarily in steam power generation,in the

Toronto area and in the steel-making process at Hamilton.

Developments involving Canadian government policy and private

industrial expansion may impact directly on the future demand for

coal at Toronto and Hamilton, respectively. The coal consuming

generating station at the port of Toronto is scheduled to become

obsolete at or about 1985 [5]. The possibility is such, however,

that coal will continue to move from Ohio ports by lake vessel for

peaking purposes at the Toronto power generating station. In

accordance with the above discussion, the future tonnage of coal

moving from U. S. ports to Eastern Canada for power generation is

not expected to continue at a growth rate such as that achieved in

[5] Department of Public Works of Canada, Future Port Requirements, Western Lake Ontario, a report by Gibb, Albery, Pullerits and Dickson, 1969, p. 78.

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TABLE D-7

U. S. Coal Traffic between Lake Erie and Lake Ontario, 1958 to 1970

COAL

YEAR	U.S. WELLAND CANAL TRAFFIC			U.S.-U.S.		U.S.-OVERSEAS		U.S.-CANADA		CANADA-U.S.	
	Total	Upbound	Downbound	Up	Down	Up	Down	Up	Down	Up	Down
1958	4,399	8	4,391	–	–	–	–	–	4,391	8	–
1959	4,647	14	4,633	–	5	–	–	–	4,628	14	–
1960	4,274	18	4,256	–	–	–	–	3	4,256	15	–
1962	4,693	24	4,669	–	–	–	–	–	4,669	24	–
1963	4,977	–	4,977	–	–	–	–	–	4,977	–	–
1964	6,331	10	6,321	–	–	–	–	10	6,321	–	–
1965	7,175	25	7,150	–	–	–	–	–	7,150	25	–
1966	7,654	–	7,654	–	–	–	–	–	7,654	–	–
1967	8,689	–	8,689	–	–	–	–	–	8,689	–	–
1968	9,793	–	9,793	–	–	–	–	–	9,793	–	–
1969	10,765	–	10,765	–	–	–	–	–	10,765	–	–
1970	10,541	–	10,541	–	–	–	–	–	10,541	–	–

SOURCE: The St. Lawrence Seaway Authority and the Saint Lawrence Seaway Development Corporation, Traffic Report of the St. Lawrence Seaway, 1962-1972.

TABLE D-8

Origin-Destination of U. S. Lake Erie-Lake Ontario Coal Traffic

YEAR 1971

COMMODITY 2 COAL

	TO									
	GREAT LAKES PORTS									
FROM PORT	LK SUP.	LK MICH.	DET'STCL	LK HURON	LK ERIE	LK ONTAR	W CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK MICH.	0.	0.	0.	0.	0.	0.	0.	7330.	0.	0.
DET'STCL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK HURON	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK ERIE	0.	0.	0.	0.	0.	0.	0.	9233572.	0.	0.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W CANADA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
E CANADA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
COASTWIS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OVERSEAS	73.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTALDOWN	0.	73.	0.	0.	0.	0.	0.	0.	0.	0.
TOTLACROS	0.	7330.	0.	0.	9233572.	9240902.	0.			
TOTAL TONS FOR THIS COMMODITY 2 COAL	IS	9240975.								

SOURCE: <u>Waterborne Commerce of the United States</u>, U. S. Army Corps of Engineers, 1971.

D-18

the 1960-1970 decade. Environmental policy decisions, related to
sulphur emissions from combustion of coal, may have a further
negative impact on the use of coal in the Canadian power industry
in future decades. Coal traffic between Lake Erie and Lake Ontario
is expected to continue in supply of the steel-making facilities at
Hamilton.

Together with antipollution constraints on the future use of
coal in industry is the price structure of coal. A relative shortage
of coal supply in recent years, coupled with increased production
costs, has increased United States coal f.o.b. mine prices from
$4.99 per ton in 1969 to $6.26 per ton in 1970 with indications that
additional price increases may be further imposed.[6]   Similar
shortages and even higher prices for natural gas and petroleum have
somewhat neutralized the increased costs of coal in the energy market.
The future of nuclear energy will play an important role in the long
range demand for U. S. coal throughout the northern hemisphere.

Based on the constraints in the production and combustion of coal
discussed above, future waterborne commerce between Lake Erie and Lake
Ontario is expected to level off at about the current level for the
next several decades. Although a slight increase in overall coal
tonnages is projected for the 1990-2040 period, the growth represents

[6]Bureau of Mines, Minerals Yearbook, "Coal - Bituminous and Lignite."
p. 327.

a relative decline in the use of coal in what is expected to

be,a rapidly increasing need for energy producing commodities.

TABLE D-9

U. S. Coal traffic between Lake Erie and Lake Ontario
1960-1971, Actual and 1980, 1990, 2015 and 2040 Projected
(000 tons)

1960-65	–	5,491
1966-70	–	9,488
1971	–	9,241
1980	–	10,500
1990	–	11,500
2015	–	14,000
2040	–	16,000

If acceptable substitutes for energy in the power and steel

industries are not forthcoming,coal could represent a larger share

of the energy market than is indicative of the slow growth in pro-

jections of future waterborne commerce illustrated in Table D- 9

On the other hand, even with an accelerated development of nuclear

power, some supplies of coal will be required as the most practical

means of peaking in power generation.

D-8   Petroleum and Products.   The distribution of fuel oil,

gasoline, and other petroleum products by tanker on the Great Lakes

has represented a small portion of the total waterborne traffic

between Lake Erie and Lake Ontario in recent years.   Traffic has

fluctuated around 500,000 tons throughout the 1958-1971 period

(Table D -10).   Illustrative of the traffic pattern is the origin-

destination matrix for 1971 shown on Table D-11.   The present break-

down by commodity shows that of the 477 thousand tons in 1971,

(1) 68 percent of the tonnage was in fuel oil, (2) 14 percent was

in gasoline, and (3) 18 percent was in other petroleum products

represented in the commodity definition shown on Table D -1   As

evidenced by the scattered traffic patterns shown in the O/D matrix,

the waterborne movement of petroleum represents a supplementary

distribution of petroleum with the main U. S. needs delivered

by pipelines, inland barge transportation, or truck short-haul.

Also of significance in the O/D breakdown is the very small direct

overseas interchange of waterborne petroleum traffic.   As shown in

Figure D-1, existing refinery capacity in the vicinity of the U. S.

Great Lakes is relatively small, compared to the current supply areas

on the Gulf Coast. With existing shortages of petroleum in the United

States and the declining off-shore capacity in the Gulf Coast area,

a change in petroleum supply and distribution pattern is probable

in the next several decades.   In a recent study of United States

petroleum supply and demand for the period from the present to the

PETROLEUM, CRUDE AND PRODUCTS

YEAR	U.S. WELLAND CANAL TRAFFIC			U.S.-U.S.		U.S.-OVERSEAS		U.S.-CANADA		CANADA-U.S.	
	Total	Upbound	Downbound	Up	Down	Up	Down	Up	Down	Up	Down
1958	1,130	171	959	164	248	–	–	–	711	7	–
1959	482	179	303	135	100	32	10	3	193	9	–
1960	343	103	240	98	189	–	13	5	38	–	–
1962	426	107	319	100	299	–	5	–	15	7	–
1963	427	132	295	84	268	–	8	–	19	48	–
1964	508	113	395	101	337	–	8	–	50	12	–
1965	513	163	345	107	289	–	10	–	46	61	–
1966	538	160	378	96	306	1	22	–	50	63	–
1967	599	87	512	80	368	–	13	–	131	7	–
1968	607	148	459	126	279	–	6	18	174	4	–
1969	481	185	296	111	243	44	2	–	51	30	–
1970	573	328	245	55	230	–	1	–	14	273	–

Source: The St. Lawrence Seaway Authority and the Saint Lawrence Seaway Development Corporation, Traffic Report of the St. Lawrence Seaway, 1958-1970.

TABLE D-11

Origin-Destination of U. S. Lake Erie-Lake Ontario Petroleum Traffic

YEAR 1971

COMMODITY 3 PETROLEM

FROM PORT	TO GREAT LAKES PORTS									
	LK SUP	LK MICH	DET.STCL	LK HURON	LK ERIE	LK ONTAR	W CANADA	F CANADA	COASTWIS	OVERSEAS
LK SUP	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK MICH	0.	0.	0.	0.	0.	0.	0.	43.	0.	2889.
DET.STCL	0.	0.	0.	0.	8334.	0.	0.	28.	0.	217.
LK HURON	0.	0.	0.	0.	0.	0.	0.	5698.	0.	109.
LK ERIE	0.	0.	0.	0.	0.	183537.	0.	76064.	38964.	4191.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W CANADA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
E CANADA	0.	0.	32772.	52036.	0.	0.	0.	0.	0.	0.
COASTWIS	0.	0.	50115.	10500.	0.	0.	0.	0.	0.	0.
OVERSEAS	0.	1429.	9654.	169.	0.	0.	0.	0.	0.	0.
TOTALDOWN	0.	1429.	92521.	5807.	62705.	191871.	0.	81933.	38964.	7406.
TOTLACROS	0.	2932.	8579.		302756.	0.	0.	84808.	60615.	11232.

TOTAL TONS FOR THIS COMMODITY 3 PETROLEM IS 476729.

SOURCE: Waterborne Commerce of the United States, U. S. Army Corps of Engineers, 1971.

D-23

FIGURE D-1. LOCATION OF PETROLEUM REFINING CAPACITY IN ONE THOUSAND BARRELS DAILY[a]
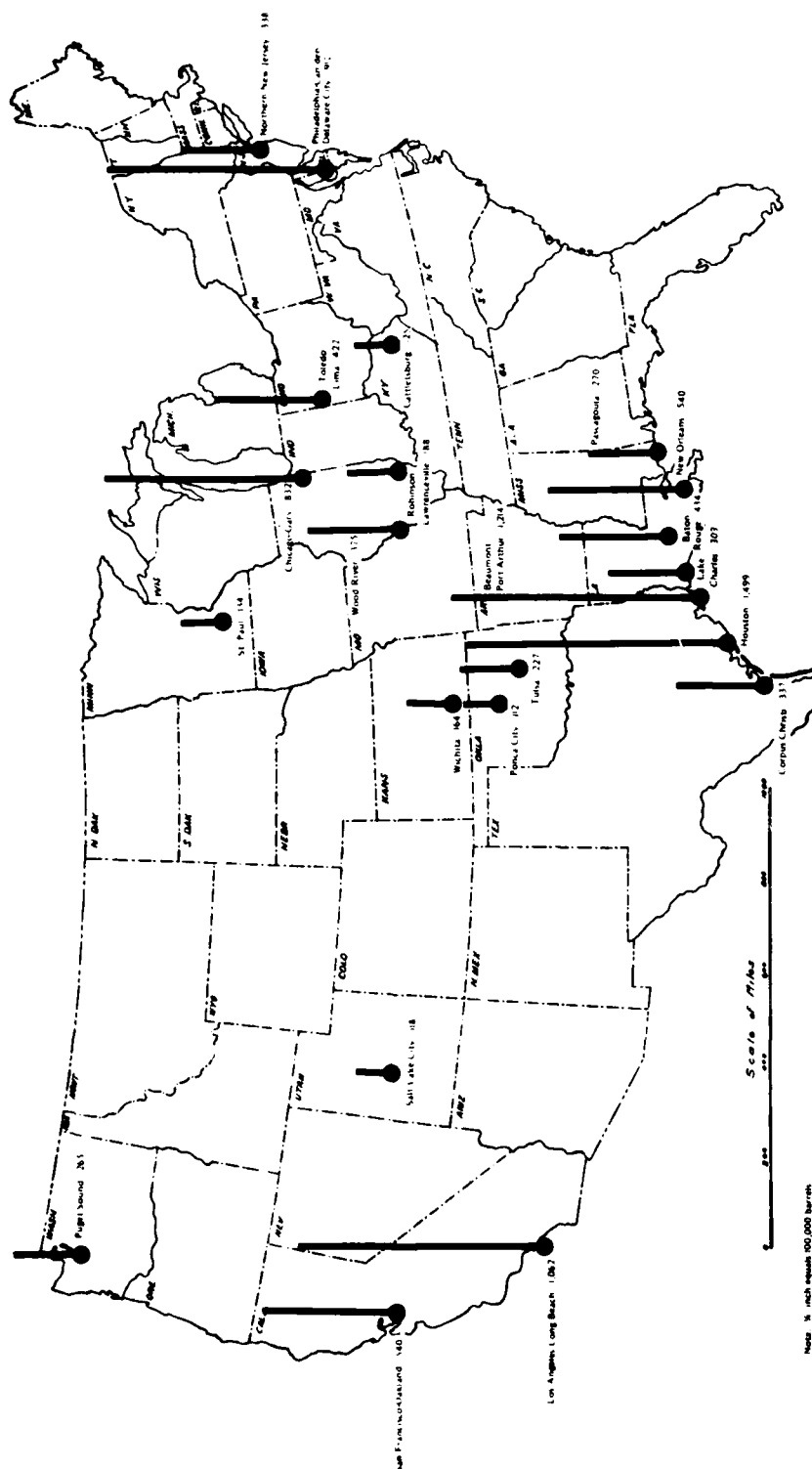
year 2000 [7] , the conclusion was reached that:

(1) The deficit in crude petroleum (over U. S. domestic production) would be 6.9 million barrels daily in 1980 and 19.7 million in 2000, compared with 1.2 million in 1970;

(2) The allocation of crude petroleum import requirements among foreign sources (in making future projections of U. S. imports) conforms to a conclusion that only the oil-producing nations of the Middle East and Africa have sufficient reserve and productive capacity to supply the bulk of the anticipated U. S. demand for petroleum from external sources of supply; and

(3) Of the total crude deficit of 6.9 million barrels daily in 1980, 4.9 million are projected as coming from Middle East and African sources, 1.9 million from Canada, and 100,000 from the Far East.

These conclusions are cited to indicate that existing sources and resulting petroleum distribution patterns will probably undergo wide changes in future years. One additional implicit conclusion is that the demand for petroleum, regardless of source of supply, will continue strong as population, leisure time, and a mobile society continue to grow.

Regardless of the source of petroleum supply, pipeline will undoubtedly continue as the most economical means of distribution. Should increasingly large volumes of crude or even refined petroleum products be imported from Middle East and African nations,

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[7] U. S. Army Corps of Engineers, Institute for Water Resources, U. S. Deepwater Port Study, Volume II, 1972.

as suggested in the above conclusions, the possibility of increased waterborne distribution from the North Atlantic Coast and the St. Lawrence river region of Canada to U. S. Great Lakes ports has a more favorable outlook. Even as a supplement to major pipeline distribution, petroleum transport by tanker utilizing the Lake Erie-Lake Ontario Waterway could develop.

Although changing patterns of supply and distribution may emerge in the decades ahead, the economies in pipeline distribution, together with the ability of deepwater coastal ports to handle tankers up to 80 feet draft, continue to weight against direct importation of petroleum at U. S. Great Lakes ports. Consequently, as shown in Table D-12, petroleum traffic is projected to increase only modestly over the next several decades and is represented as a continuance of the present supplemental distribution system in the 1990-2015 study period. Major increases in Atlantic Coast and overseas waterborne shipment of petroleum are not projected at this time, since no supportable evidence is available to indicate that direct waterborne shipments from these terminals and basic petroleum sources are likely int ^he Great Lakes in the forseeable future.

TABLE D-12

U. S. Petroleum Traffic Between Lake Erie and Lake Ontario
1960-1971, Actual, and 1980, 1990, 2015 and 2040 Projected
(000 tons)

1960-65	-	443
1966-70	-	560
1971	-	477
1980	-	600
1990	-	750
2015	-	1,250
2040	-	2,000

D-9 Clay, Stone, Cement, Sand, and Gravel. Construction related commodities such as clay, stone, cement, sand, and gravel have shown steady traffic on the Great Lakes in recent years. The general pattern for existing waterborne traffic in construction materials between Lake Erie and Lake Ontario, as illustrated in O/D matrix Table D-13, represents:

(1) a large movement of ground and crushed stone from the vicinity of West Lake Ontario to Lake Erie ports of Cleveland and Fairport, (2) over a quarter of a million tons of sand and gravel and clay and bentonite from Lake Michigan ports of Chicago and Ferrysburg (Mich.) to Canadian ports at Port Weller and Hamilton; and (3) over 200,000 tons of structural clay products, including refractories to and from overseas ports.

Both the U. S. and Canadian Great Lakes port areas and hinterlands include an abundance of sand, gravel, and quarried materials which lend favorably to the comparatively high volume, low cost combination represented in waterborne transportation. A breakdown of the building materials currently moving to and from U. S. Great Lakes ports via the Welland Canal are shown on Table D-14.

Projected new construction activity for the United States shows a 3-fold increase in terms of constant 1960 dollar value between 1970 and 2000[8]. Increased construction activity together with the abundance supply of construction-related raw materials in the U. S. and Canadian Great Lakes region,

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[8] Resources for the Future, Resources in America's Future, John Hopkins Press, 1963.

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TABLE D -13

Origin-Destination of U. S. Lake Erie-Lake Ontario Clay, Cement, Stone, Sand and Gravel Traffic

YEAR 1971

COMMODITY 4 CSSG

GREAT LAKES PORTS

FROM PORT	LK SUP.	LK MICH.	DET.STCL	LK HURON	LK ERIE	LK ONTAR	N CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0.	0.	0.	0.	0.	0.	0.	59113.	0.	0.
LK MICH.	0.	0.	0.	0.	0.	0.	0.	274153.	0.	130141.
DET.STCL	0.	0.	0.	0.	0.	0.	0.	22.	0.	2857.
LK HURON	0.	0.	0.	0.	0.	150410.	0.	48995.	0.	50.
LK ERIE	0.	0.	0.	0.	0.	0.	0.	83335.	0.	8489.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
N CANADA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
E CANADA	0.	96.	80764.	0.	894657.	0.	0.	0.	0.	0.
COASTWIS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OVERSEAS	23.	50773.	6764.	0.	50328.	0.	0.	0.	0.	0.
TOTALDOWN	23.	50869.	87408.	0.	944985.	150410.	0.	465518.	0.	141537.
TOTLACROS	59113.	464294.	2879.	199355.	91824.	0.	0.	975457.	0.	77828.
TOTAL TONS FOR THIS COMMODITY 4 CSSG IS 1810750.

SOURCE: Waterborne Commerce of the United States, U. S. Army Corps of Engineers, 1971.

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TABLE D-14

Distribution of Construction Materials
U. S. Traffic Between Lake Erie and Lake Ontario

Commodity	1971 Percent of Total Traffic
Sand, Gravel and Crushed Stone	63
Clay, Ceramic and Refractory Materials	17
Building Cement	13
Limestone flux and Calcareous Stone	6
Other	1
Total	100

supports the conclusion that a continued steady traffic with modest

growth will continue between Lake Erie and Lake Ontario and overseas

ports in future decades. Projections in Table D-15 represent a con-

tinuance of existing trends with the major future traffic interchange

between U. S. Lake Michigan and Lake Erie and Canadian Lake Ontario

ports involving crushed stone, clay and bentonite, and building cement.

TABLE D - 15

U. S. Clay, Cement, Stone, Sand and Gravel Traffic
Between Lake Erie and Lake Ontario
1960-1971, Actual and 1980, 1990, 2015 and 2040 Project
(000 tons)

1960-65	- 1,434
1966-70	- 1,785
1971	- 1,811
1980	- 2,200
1990	- 2,750
2015	- 3,800
2040	- 5,000

D-10   Iron Ore. Waterborne movement of iron ore is the leader
in terms of the largest annual tonnage moved both on the U. S.
Great Lakes and in traffic between Lake Erie and Lake Ontario.
Iron ore accounted for 39 percent of total U. S. Great Lakes
waterborne commerce in 1971 and 27 percent of U. S. traffic
through the Welland Canal during the same year. From all indi-
cations an important position of iron ore,in terms of future
waterborne traffic volume,will continue in the coming decades.

The United States produced a total of 89.8 million tons of
iron ore in 1970. Of the total the U. S. Great Lakes states of
Minnesota, Michigan,and Wisconsin accounted for 78 percent.
At present about 70 percent of United States steel producing
capacity is located directly on the Great Lakes. In 1970, to
supplement domestic production of iron ore, the United States
imported an additional 44.9 million tons. Iron ore imports came
primarily from Canada (53 percent) and Venezuela (29 percent).
Canada produced 48.3 million tons of iron ore in 1970,of which
23.9 million tons were exported to the United States (14.4 million
tons via the Welland Canal). At present about 90 percent of
Canadian domestic steel capacity is located directly on the
Great Lakes, primarily in Lake Ontario around Hamilton and in
the St. Marys River area between Lake Superior and Lake Huron
at Sault Ste. Marie (Ontario).

The existing iron ore traffic between the Western U. S.
Great Lakes and the Lake Ontario - St. Lawrence Region, reflecting
the location of the steel producing areas, is shown in O/D matrix
Table D- 16.   The historical breakdown of iron ore traffic through
the Welland Canal is shown in Table D- 17.   A number of studies have
been made in recent years which examine the future production and
distribution of iron ore between United States and Canada. A dis-
cussion of the finding s of several of these studies is presented
herein as a basis for a current assessment of the future Lake Erie-
Lake Ontario iron ore traffic potential.

The United States Bureau of Mines completed a study in 1970
with projections of U. S. iron ore production and transportation of
iron ore, among other commodities to the year 1995[9]   Table D - 18
is taken from that report [10] and presents production and shipments
of iron ore on the Great Lakes from 1975 to 1995. The report
summarizes the table as follows: "Imports of iron ore as handled
over the Great Lakes Waterway have in recent years accounted for
approximately 20 percent of the total Great Lakes iron ore commerce.
Principally from Canadian sources, these imports are expected to remain
at the same percentage level throughout the projection period (1975-1995)."

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[9] Transportation of Iron Ore, Limestone and Bituminous Coal on the
Great Lakes Waterway System, United States Department of the Interior.
Bureau of Mines, 1970.
[10] d.o., page 6.

TABLE D-16

Origin-Destination of U. S. Lake Erie-Lake Ontario Iron Ore Traffic

YEAR 1971

COMMODITY 5 IRON ORE

FROM PORT	TO GREAT LAKES PORTS									
	LK SUP.	LK MICH.	DET;STCL	LK HURON	LK ERIE	LK ONTAR	W CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK MICH.	0.	0.	0.	0.	0.	0.	0.	0.	0.	217.
DET;STCL	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK HURON	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK ERIE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W CANADA	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
E CANADA	3920.	3210048.	739401.	0.	6887098.	0.	0.	1325669.	0.	0.
COASTWIS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OVERSEAS	0.	0.	27565.	0.	18.	0.	0.	0.	0.	0.
TOTALDOWN	3920.	3210048.	261986.	0.	6887116.	0.	0.	1325669.	0.	0.
TOTLACROS	1325669.	217.	217.	0.	0.	0.	0.	10339467.	0.	217.

TOTAL TONS FOR THIS COMMODITY 5 IRON ORE IS 11688976.

D-32

SOURCE: Waterborne Commerce of the United States, U. S. Army Corps of Engineers, 1971.

TABLE D -17

U. S. Lake Erie-Lake Ontario Iron Ore Traffic by Direction, 1958-1970

YEAR	U.S. WELLAND CANAL TRAFFIC			U.S.-U.S.		U.S.-OVERSEAS		U.S.-CANADA		CANADA-U.S.	
	Total	Upbound	Downbound	Up	Down	Up	Down	Up	Down	Up	Down
1958	4,291	1,859	2,432	–	–	–	–	–	2,432	1,859	–
1959	7,055	5,256	1,799	–	–	–	–	–	1,799	5,256	–
1960	7,926	4,257	3,669	–	–	52	–	–	3,669	4,205	–
1962	10,114	6,260	3,854	–	–	9	61	–	3,793	6,251	–
1963	12,630	8,354	4,276	–	–	12	–	–	4,276	8,342	–
1964	16,775	12,680	4.095	–	–	–	–	–	4,095	12,680	–
1965	16,054	12,152	3,902	–	–	6	–	–	3,902	12,146	–
1966	17,458	13,850	3,608	–	–	–	–	–	3,608	13,850	–
1967	16,500	14,092	2,408	–	–	–	–	–	2,408	14,092	–
1968	17,735	15,365	2,370	–	–	–	–	–	2,370	15,365	–
1969	12,454	10,303	2,151	–	–	–	–	–	2,151	10,303	–
1970	14,432	12,525	1,907	–	–	–	–	–	1,907	12,525	–

SOURCE: The St. Lawrence Seaway Authority and the Saint Lawrence Seaway Development Corporation, Traffic Report on the St. Lawrence Seaway, 1962-1972.

TABLE D-18 – Projected Great Lakes area iron ore productions and
Great Lakes shipments, million net tons

	Base year, 1960	1970	1975	1980	1985	1990	1995
Production...............	75.1	87.2	93.9	101.2	109.0	117.4	126.5
Shipments:							
Lakewise...............	–	76.6	82.1	88.4	95.3	102.7	110.7
Export.................	–	5.2	5.1	5.0	4.9	4.8	4.8
Import.................	–	21.5	24.0	25.3	26.9	28.4	30.1

A second study, also completed in 1970, was conducted by

D. W. Carr and Associates, Ltd. for the St. Lawrence Seaway

Authority of Canada.[11]   Tables D - 19 and D -20 are quoted

from that report. Discussion on the tables from the report are

quoted:

"The estimated distribution by origin of iron ore

to supply the United States requirements in 1985 is

expected to be as shown in Table D -19...... Based on

the estimated Canadian and United States consumption

levels of iron ore, the traffic in this commodity on

the St. Lawrence Seaway by 1985, is summarized in Table D -20 ".

[11] The Seaway in Canada's Transportation, Volume 2, D. W. Carr
and Associates, Ltd., Ottawa, 1970.

TABLE D - 19

UNITED STATES IRON ORE CONSUMPTION BY

SOURCE PROJECTIONS, 1985

SOURCE	VOLUME	PROPORTION
	(millions of short tons)	(per cent)
Quebec-Labrador via Seaway	19.0	12
Quebec-Labrador via Atlantic Ports	12.5	8
Great Lakes-Canada	6.5	4
Great Lakes-United States	88.0	55
Other United States	16.0	10
Other Foreign	17.5	11
Total	159.5	100

TABLE D - 20

PROJECTED TRAFFIC IN IRON ORE, CANADA AND

UNITED STATES VIA SEAWAY ROUTES, 1985

From	To	MONTREAL-LAKE ONTARIO SECTION	WELLAND SECTION
		(millions of short tons)	
Canadian Destinations			
Quebec-Labrador	Lake Ontario	5.2	-
Lake Superior	Lake Ontario	-	2.0
United States Destinations			
Quebec-Labrador	Great Lakes	19.0	19.0
Total		24.2	21.0

SOURCE; The Seaway in Canada's Transportation, An Economic Analysis, Vol. 2, Dec. 1970.

United States production of iron ore is one of the major
variables which affect the volume of imports required to supple-
ment steel production. Since the completion of the U. S. Bureau
of Mines and Canadian St. Lawrence Seaway Authority sponsored
report in 1970, U. S. production levels have risen and import
levels in iron ore have fallen off, somewhat, from trends in the
last half of the 1960-decade. Present indications are that,
although traffic levels may not reach the projected levels shown
in Tables D-18 and D-20 above, that continued U. S. requirements
for iron ore will be met by increases in domestic production as
well as from import sources. Further, taking into consideration
the gradually increasing iron content in both U. S. and Canadian
iron ore concentrates, projections of future iron ore traffic
between Lake Erie and Lake Ontario are shown in Table D ·21.

TableD - 21

U. S. Iron Ore Traffic Between Lake Erie and Lake Ontario
1960-1971, Actual and 1980, 1990, 2015 and 2040 Projected
(000 tons)

1960-65	- 12,700
1966-70	- 15,716
1971	- 11,689
1980	- 16,000
1990	- 20,000
2015	- 30,000
2040	- 40,000

D-11 <u>Other Bulk.</u> Miscellaneous bulk commodities accounted for slightly less than 5 percent of United States traffic utilizing the Welland Canal between Lake Erie and Lake Ontario in base year 1971. Table D-22 presents a breakdown of the other bulk traffic by commodity. A wide fluctuation occurs among the other bulk commodities from year to year making long term forecasts difficult in terms of establishing a growth rate for the commodity group as a whole. Commodities which move with some consistency are: (1) salt, (2) newsprint, and (3) coke. Table D-23 is the O/D matrix for other bulk commodities moving through the Welland Canal in 1971.

TABLE D-22

Distribution of Other U. S. Bulk Waterborne Commerce
Between Lake Erie and Lake Ontario

1971

	Tons (000)	Percent
Total	2,120.5	100
Manganese Ores	129.1	6.1
Nonferrous Ores	93.4	4.4
Bauxite	19.6	.9
Standard Newsprint	224.1	10.6
Other Pulp and Paper	42.1	2.0
Salt	353.7	16.7
Nonmetallic Minerals	215.5	10.2
Crude Rubber	136.3	6.4
Veneer and Plywood	80.3	3.8
Coke	459.4	21.6
Miscellaneous	367.0	17.3

TABLE D-23

Origin-Destination of U. S. Lake Erie-Lake Ontario Other Bulk Commodities

YEAR 1971

COMMODITY 6 OTH BULK

FROM PORT	TO GREAT LAKES PORTS									
	LK SUP.	LK MICH.	DET;STCL	LK HURON	LK ERIE	LK ONTAR	W CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4962.
LK MICH.	0.	0.	0.	0.	0.	0.	0.	256542.	0.	45683.
DET;STCL	0.	0.	0.	0.	0.	0.	0.	215363.	0.	32409.
LK HURON	0.	0.	0.	0.	0.	0.	0.	0.	0.	18.
LK ERIE	0.	0.	0.	0.	0.	106800.	0.	152484.	0.	164629.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W CANADA	0.	0.	0.	0.	0.	7935.	0.	0.	0.	0.
E CANADA	0.	192722.	81898.	0.	202391.	0.	0.	0.	0.	0.
COASTWIS	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OVERSEAS	2543.	192144.	167316.	411.	300994.	0.	0.	0.	0.	0.
TOTALDORN	2543.	394868.	242204.	411.	503375.	0.	0.	624589.	0.	247692.
TOTLACROS	4962.	352225.	247772.	18.	424104.	114735.	7935.	477001.	0.	656440.

TOTAL TONS FOR THIS COMMODITY 6 OTH BULK IS 2120457.

For projection purposes, the potential for new bulk commodity groups, together with the continuation of the present miscellaneous commodities, was viewed as having a direct correlation with the overall growth in LE-LO traffic. Much of the miscellaneous traffic occurs as the result of available backhaul space on regular commodity movements and thus is a function of available space and low cost transportat'⌐, which enables the movement of low value commodities for relatively long distances at reasonable rates. Table D-24 presents the projected growth of other bulk traffic utilizing the Lake Erie-Lake Ontario Waterway in future decades.

TABLE D-24

U. S. Other Bulk Commodity Traffic Between Lake Erie and
Lake Ontario, 1971, Actual and 1980, 1990, 2015 and 2040 Projected
(000 tons)

1971 - 2,121
1980 - 2,600
1990 - 3,100
2015 - 4,500
2040 - 6,000

D-12   General Cargo. General cargo has been characterized as

items of cargo which form discreet units -- packages, boxes, bales,

individual pieces of machinery -- as contrasted with cargo which

flows and which can be handled by gravity methods or by pumps.

General cargo is very diversified and includes most manufactures

and other items of high value in proportion to the space which they

occupy. The value per ton of general cargo, and consequently the

ability of the cargo to move at higher freight rates, is generally

much greater than that of bulk cargo .[12] Because of the high value of

most general cargo commodities,the transport economies covering low

value-high volume bulk cargo do not apply.

TABLE D -25

Distribution of U. S. General Cargo
Waterborne Commerce Between Lake Erie and Lake Ontario

1971

	Tons (000)	Percent %
Total	9,300	100
Iron and Steel	6,102	65.4
Other Primary Metal Prod.	105	1.1
Chemicals	347	3.7
Food	2,226	23.9
Transportation Equipment	203	2.2
Machinery	213	2.3
Other Manufacture	134	1.4

[12] U. S. Army Corps of Engineers, General Cargo Traffic Analysis, 1967.

That is, the greater risk of damage and pilferage in general cargo movements, together with the high unit value, place transportation charges in a different perspective as compared to bulk cargo. The chief advantage of waterborne transport service is in the high volume-low cost combination represented in liner-type cargo vessels. Speed of delivery and flexibility in distribution, other than from seaport to seaport, are limiting factors.

Table D-25 shows a breakdown of U. S. general cargo commodities which moved through the Welland Canal in 1971. Table D-26 is a corresponding matrix of origin and destination by area for the 1971 traffic. Salient points represented by the O/D matrix are:

(1) 8.8 million tons or 95 percent of the 9.3 million tons of general cargo moving between Lake Erie and Lake Ontario in 1971 had origin or destination at overseas ports;

(2) of the 8.8 million tons of overseas general cargo, 6.0 million tons or 61 percent originated overseas, and

(3) conversely, only 2.8 million tons of general cargo was shipped overseas from U. S. ports.

TABLE D-26

Origin-Destination of U. S. Lake Erie-Lake Ontario General Cargo

YEAR 1971

COMMODITY 7 GN CARGO

FROM PORT	TO GREAT LAKES PORTS								COMMODITY 7 GN CARGO	
	LK SUP.	LK MICH.	DET;STCL	LK HURON	LK ERIE	LK ONTAR	W CANADA	E CANADA	COASTWIS	OVERSEAS
LK SUP.	0.	0.	0.	0.	0.	0.	0.	0.	0.	520229.
LK MICH.	0.	0.	0.	0.	0.	0.	87981.	0.	0.	169299.
DET;STCL	0.	0.	0.	0.	0.	0.	11413.	0.	22966.	281979.
LK HURON	0.	0.	0.	0.	0.	0.	3373.	0.	15582.	104279.
LK ERIE	0.	0.	0.	0.	0.	0.	1044.	0.	63044.	195984.
LK ONTAR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
W CANADA	0.	0.	0.	0.	0.	10951.	0.	0.	0.	0.
E CANADA	5.	45930.	29755.	40287.	66810.	0.	0.	0.	0.	0.
COASTWIS	0.	90.	17911.	0.	57248.	700.	0.	0.	0.	0.
OVERSEAS	84091.	2315561.	2708473.	16817.	1326579.	0.	0.	0.	0.	0.
TOTALDOMN	84096.	2361381.	2356049.	57104.	1450637.	11651.	0.	102911.	101592.	2784940.
TOTLACROS	520220.	1770071.	315982.	123228.	259972.	0.	10951.	262787.	75949.	6051271.

TOTAL TONS FOR THIS COMMODITY 7 GN CARGO IS 9330401.
GRAND TOTAL OF TONNAGE IS 43297272.

SOURCE: Waterborne Commerce of the United States, U. S. Army Corps of Engineers, 1971.

The U. S. imports of General Cargo may be discussed, almost exclusively, in terms of iron and steel products. Of the 6.0 million tons of general cargo imports in 1971, iron and steel in various forms represented 5.4 million tons. The iron and steel is categorized as bars, rods, angles, shapes, sections, plates, and sheets. Major overseas imports were received at Detroit (including River Rouge), Chicago, and Cleveland with lesser amounts received at Toledo and Milwaukee.

Exports of general cargo from the United States to overseas ports were mainly in the form of wheat flour and other grain meal products, which accounted for about 1.1 million tons or 40 percent of the U. S. overseas total. The remaining U. S. general cargo exports were widely distributed among other food and kindred products, iron and steel products, machinery and transportation equipment. General cargo receipts at U. S. ports via the Welland Canal from Eastern Canada amounted to slightly more than 200 thousand tons of which 66 percent were in iron and steel and 18 percent in chemical products. U. S. general cargo shipments to Eastern Canada were widely diversified in small amounts mainly in iron and steel, including scrap, and food products. The U. S. - Coastwise traffic included mainly petro-chemical products.

The future outlook for increasing general traffic at Great Lakes ports depends to a large extent on the competitive relationship

with Atlantic Coast and Canadian St. Lawrence River general

cargo port facilities. An increasing share of general cargo,

including iron and steel, is expected to be packaged and container-

ized in future years. The ability of Great Lakes ports to become

competitive in terms of cost, quality, and timeliness of service

with coastal ports will play a large role in the growth of general

cargo traffic. Further discussion on the subject of containerization

is contained in the next section on Transportation Rate Analysis which

follows this section. A study completed by the U. S. Army Corps

of Engineers in 1967[13], concluded that less than 50 percent of the

overseas general cargo traffic generated in a 19-State Great Lakes

Tributary area is now moving via the U. S. Great Lakes ports.

A follow-up origin-destination study of U. S. General Cargo Traffic,

completed in 1972, supported the earlier conclusion that the Great

Lakes are transporting only a portion of the general cargo moving

out of the mid-continent region[14].

    United States manufactures of general cargo constituents have

been correlated with national growth parameters in recent years.

The resulting conclusion is that the growth in production of

manufactures lies at the lower end of the range represented by

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[13] U. S. Army Corps of Engineers, North Central Division, Great Lakes-Overseas General Cargo Traffic Analysis, 1967. p. 125.

[14] U. S. Department of Commerce, Bureau of the Census, Domestic and International Transportation of U. S. Foreign Trade: 1970, Sept. 1972.

population growth and gross national products. Current projections of U. S. population and GNP growth are shown in Table D - 27 and show a rate of growth for population between 1968 and 2020 at 1.3 percent per year compared with GNP at 4.0 percent per year for the same period. A resulting conclusion is that U. S. production of general cargo commodities will increase about 2 percent per year in the 1970-2020 period. As discussed above, the production of general cargo in a 19-State Great Lakes region has historically been substantially higher than waterborne distribution of general cargo on the Great Lakes. This trend is expected to continue with the Great Lakes facing competition for both exports and imports, as well as the domestic distribution of general cargo commodities. However, the backhaul principle (particularly for grain exports) will continue to make vessel capacity available for Great Lakes imports of iron and steel and a foreign demand for grain mill products, specialized manufactures, and other general cargo items will continue to result in modest export increases in general cargo via Great Lakes ports. The projections shown in Table D-28 represent slightly higher than 1 percent per year growth in the 1980-2040 period.

TABLE D - 27

PROJECTION OF NATIONAL ECONOMIC GROWTH INDICATORS

Year	Population (thousands)	Gross National Product (millions of 1958 dollars)
1950	152,271	355,878
1955	165,931	437,963
1960	180,684	487,682
1965	194,592	617,799
1966	196,920	658,087
1967	199,118	674,628
1968	201,166	707,608
Rate of increase		
1950-1968	1.6%	3.9%
1980	235,212	1,153,873
2000	307,803	2,505,894
2020	400,053	5,423,135
Rate of increase		
1968-2020	1.3%	4.0%

SOURCE: 1972 OBERS Projections, Volume 1, Concepts, Methodology, and Summary Data.

TABLE D-28

U. S. General Cargo Traffic Between Lake Erie and Lake Ontario
1960-1971 Actual and 1980, 1990, 2015 and 2040 Projected

1960-65	-	4,982
1966-70	-	8,917
1971	-	9,330
1980	-	10,500
1990	-	12,000
2015	-	16,000
2040	-	20,000

SUMMARY - FUTURE UNITED STATES AND CANADIAN TRAFFIC

D-13 Total United States waterborne traffic between Lake Erie and Lake Ontario, representing an aggregation of the seven commodity groups discussed above, is projected to increase from 43.3 million tons in 1971 to 63.6 in 1990, 89.5 in 2015, and 115.0 in 2040. The projected traffic reflects a rate of growth approximating 1.4 percent per year on a compounded basis. This compares with the historical growth rate of 4.4 percent in the 1963-1972 accelerated growth period.

Table D-29 is a summary of United States traffic by commodity group for the base year of 1971 and for each of the projection periods: 1980, 1990, 2015, and 2040. The table illustrates the projected growth in iron ore and grain and the relative decline, in terms of percentage of total traffic, for coal and general cargo.

Table D-30, D-31, and D-32 are a summary breakdown of total United States and Canadian existing and projected traffic between Lake Erie and Lake Ontario. The projections of Canadian traffic, i.e., traffic not having an origin or destination at U. S. ports, are primarily trend analyses with a slight increase in the Canadian share of overall traffic based on a projected continuance of recent growth in Canada to Canada domestic traffic brought about by the urban development in the Hamilton-Toronto and Montreal areas. Such development in the Lake Ontario region of Canada is expected to continue in future decades and is the basis for expected growth in waterborne traffic between the raw materials supplying middle provinces and the heavily populated consuming area east of the Lake Erie-Lake Ontario Waterway.

TABLE D -29

Summary of U. S. Waterborne Traffic Between Lake Erie and
Lake Ontario, 1971 Actual, and 1980, 1990, 2015 and 2040 Projected

	1971 [15]	1980	1990 (000 tons)	2015	2040
Grain	8,629	11,000	13,500	20,000	26,000
Coal	9,241	10,500	11,500	14,000	16,000
Petroleum	477	600	750	1,250	2,000
CCSSG	1,811	2,200	2,750	3,800	5,000
Iron Ore	11,689	16,000	20,000	30,000	40,000
Other Bulk	2,120	2,600	3,100	4,450	6,000
Gen. Cargo	9,330	10,500	12,000	16,000	20,000
Total	43,297	53,400	63,600	89,500	115,000

(Percent)					
Grain	20	20	21	22	23
Coal	21	20	18	16	14
Petroleum	1	1	1	1	2
CCSSG	4	4	4	4	4
Iron Ore	27	30	32	34	35
Other Bulk	5	5	5	5	5
Gen. Cargo	22	20	19	18	17
Total	100	100	100	100	100

[15] U. S. Army Corps of Engineers, Waterborne Commerce of the United States, 1971.

TABLE   D-30

Total U. S. Waterborne Commerce Between Lake Erie
and Lake Ontario - 1960-71, Actual,
and 1980, 1990, 2015 and 2020 Projected

1960-65	-	31,748
1966-70	-	44,444
1971	-	44,150
1980	-	53,400
1990	-	63,600
2015	-	89,500
2040	-	115,000

TABLE   D-31

Total Canadian 16Waterborne Commerce Between
Lake Erie and Lake Ontario 1960-71 Actual,
and 1980, 1990, 2015 and 2040 Projected

1960-65	-	10,399
1966-70	-	12,866
1971	-	18,759
1980	-	24,600
1990	-	30,400
2015	-	42,500
2040	-	55,200

TABLE   D-32

Total U. S. and Canadian Waterborne Traffic Between
Lake Erie and Lake Ontario, 1960-71 Actual,
and 1980, 1990, 2015 and 2040 Projected

	United States	Canada	Total
1960-65	31,748	10,399	42,147
1966-70	44,444	12,866	57,310
1971	44,150	18,759	62,909
1980	53,400	24,600	78,000
1990	63,600	30,400	94,000
2015	89,500	42,500	132,000
2040	115,000	55,000	170,000

16 Includes Canada - Canada and Canada-Overseas; Canada-U. S. Traffic
include with U. S. Totals

INTRODUCTION

D-14 The competitive position of the Great Lakes-St. Lawrence Seaway system, as an alternative to routings to and from interior points via traditional coastal ports of entry or exit, has been a subject of interest and research ever since the Seaway became a reality, with passage of the enabling legislation in 1954. In the years since the Seaway opened in 1959, many changes have taken place within the United States economy and the realm of world shipping. Technological changes have been accepted as part of the norm, and internal adjustments of commodity flows, present and projected, have necessitated new evaluations of existing trade arteries. Earlier work in the study field centered upon hinterland definition, projections of traffic flows, assessment of economic benefits to be derived from the new route, determination of specific cases of freight rate advantage or disadvantage and analysis of regional freight rate structures as related to the important commodity movements. 1

The need for an updated rate study is a reflection of the impact of economic growth, technological change, and internal changes of commodity flows. Anticipated demands on the existing Welland Canal from both

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U. S. Army Engineer Division, North Central, Great Lakes Harbors Study, Summary Report, November 1966.

Stanford Research Institute, Economic Analyses of St. Lawrence Seaway Cargo Movements and Forecasts of Future Cargo Tonnage, U. S. Department of Commerce Contract No. C-194-65(Neg.), November 1965.

J. Kates and Associates, St. Lawrence Seaway Tolls and Traffic-Analyses and Recommendations, The St. Lawrence Seaway Authority, December 1965.

EBS Management Consultants Incorporated, An Economic Analysis of Improvement Alternatives to the St. Lawrence Seaway System, U. S. Department of Transportation Contract No. DOT-OS-A8-018, January 1969.

Great Lakes Basin Framework Study, Appendix No. 9, Volume 1, Commercial Navigation - Draft No. 2, Navigation Work Group - Great Lakes Basin Commission, February 1972.

Executive Summary Relationship of Land Transportation Economics to Great Lakes Traffic Volume, U. S. Department of Commerce Maritime Administration, Contract No. 1-35492, October 1971.

Snavely, King and Tucker, Incorporated. A study of the Effects of Inland Freight Rates and Services on the St. Lawrence Seaway. Washington, D. C. 15 December 1971.

Draine ,Edwin H, Freight Rate Structure, Transportation Division, Chicago Association of Commerce and Industry, January, 1965.

the United States and Canadian economies are such that the physical capacity of the present system will be exceeded in the late 1980's. Technological development is evident in the form of ship size, containerization of cargo, and the LASH system for the inland water shallow draft system served by the Gulf Coast.

Internal changes in commodity flows may be expected to result from new competitive forces in the movement of coal and iron ore. The existing pattern of coal movements undoubtedly will be influenced by increased Canadian demand, and the impact of environmental rulings may be expected to result in realignments of existing flows. Throughout the present century, iron ore has moved downlake from the upper lakes to Chicago, Detroit, Cleveland and other lower lakes'ports. An upbound iron ore movement, from St. Lawrence River points, to the United States steel centers above the Welland Canal, has recently developed. Over the period of the next fifty years, this may be expected to become increasingly significant. Overseas demand for midwestern agricultural products has increased dramatically in recent years. The efficiency of the Seaway system will be an important component factor in moving this grain overseas without overburdening the domestic inland transportation system.

As part of the overall Lake Erie-Lake Ontario Study, the research effort centering upon comparative freight rates has the purpose of providing substantive data to assist in development of the overall benefit/cost ratio. A thorough study of the relative rates for selected commodity movements has been undertaken, leading to the identification of the routings with the least alternative costs. In turn, application of this factor of advantage to the commodity flow data, expressed in dollars, contributes to the overall benefit/cost ratio for the present and projected commodity movement.

GENERAL CARGO O/D STUDY

D-15   In September 1972, the Bureau of Census published the study Domestic and International Transportation of U. S. Foreign Trade: 1970. This survey was sponsored jointly by the U. S. Army Corps of Engineers and the U. S. Department of Transportation. Corps' funding for the study was provided by the Buffalo District through the North Central Division and by the Institute for Water Resources. Survey data were collected and processed by the Transportation Division of the Bureau of Census.

The survey was undertaken to obtain new data on the domestic movement of foreign trade and to link these new facts with already available information on the international aspects of the commodity

flows. The report includes general cargo commodities, moving internationally by vessel and air. The information on the domestic movement includes the commodity weight and value, the major means of transportation between significant points, and the distance moved. U. S. geographic points are designated for the State and for the production/market area. Data on the international movement includes month of shipment or receipt, customs district and port, and overseas trading area.

RATE STUDY TO DETERMINE LEAST COST ROUTING OF GREAT LAKES AREA CARGOES

D-16   The above origin-destination data on liner-type, general cargo and origin-destination data on bulk commodities, developed in an NCD study for the Upper Great Lakes Regional Commission, serve as a basis for addressing transportation costs for waterborne and competing overland transport modes. Net differential in transportation costs will be correlated with prevailing transportation rates to provide the basis for determination of unit transportation savings and benefits in accordance with Section 7(a) Transportation Act (PL 89-670), 1966. First a representative list of commodities produced or consumed in the Great Lakes Area and entering the trade stream overseas was selected. The sources of information included Census of Manufactures, Survey of the Origin of Exports of Manufactured Products, Waterborne Commerce, statistics of the Corps of Engineers, past studies of Dr. Edwin H. Draine, NCD, Consultant. The Chicago Association of Commerce and Industry's U. S. Great Lakes Ports Monthly Statistics for Overseas and Canadian Waterborne Traffic also was helpful in narrowing down the list of commodities to be included in the study.

The Bureau of Census origin-destination computer tapes were then analyzed for the following information on the selected 41 commodities: Production Area or Market Area of origin and destination (PA&MA's are groups of closely related SMSA's;) State of origin or destination; Customs District and port of entry or exit; overseas trading area of ports; and data on containerization susceptibility. Additional domestic origins were pinpointed through use of the Thomas Register of Manufacturers.

Closely related to selection of the origin-destination sites was the selection of appropriate ports of entry or exit. In every case, at least one Great Lakes port was included for every commodity, but the coastal ports varied with the characteristics of the commodity movement under consideration. The commodities selected for detailed investigation are important and representative components of the trade pattern. Having selected the commodities, a detailed description of articles within the commodity classification had to be developed so that applicable freight rates, both overland and ocean, could be obtained. The commodities were divided into export-import categories with appropriate interior or overseas origin and **destination points or areas.**

With the commodities selected, it was then necessary to assign representative coastal and Great Lakes ports as points of entry or exit. For each commodity the appropriate Great Lakes port or ports were selected with the choice of the coastal ports being contingent upon the overseas area to be served.

The interior portion of the movement was covered by rates via either rail, truck or barge; and in the case of the barge rates a combination rate for barge plus rail or truck was obtained when applicable. The rates covered the movement from or to the ports already selected. In contrast to the United States interior sites as either points of origin or destination, the overseas positions were identified as geographic areas of origin or destination. Thus a range of overseas ports generally served as the origin or destination for the rates used in this study.

The individual factors required in developing the overall rate for a specific movement were obtained from a number of sources. The basic rates for the overland portion of the movement, both rail and truck, were provided by Eastern Area Military Traffic Management and Terminal Service, Brooklyn, New York. They consisted of the lowest applicable January 1973 rate, either commodity or class, from the published tariffs. The deep water rates applicable during Autumn 1972 were obtained from individual water carriers or their agents to the extent possible. For water rates that could not be obtained from individual firms the Federal Maritime Commission in Washington, D. C. provided information from their public files. A figure for the "open" or "negotiated" rates on grains was developed by taking the average of the "tramp rates" for port-to-port movements for a 4-month period (September through December) as published in Maritime Research Incorporated, Chartering Annual, 1972.

All water rates, whether weight or measure were reduced to a hundred-weight basis. With the above information in hand, all the rate data were reduced in final form to the standard of cents per hundredweight. Weight cargo in Long (2240 lbs.), Metric (2204 lbs.), and Short (2000 lbs.) tons were divided appropriately. Measurement cargo was converted to a hundred-weight basis through use of one stowage factor for each commodity.

> "The stowage factor is the space in cubic feet
> occupied by a long ton of a commodity, packed
> for shipment. This factor is computed by divi-
> ding a long ton (2240 lbs.) by weight in pounds,
> of a cubic foot of the packed commodity. A

shipping ton is 40 cubic feet in measurement,
and commodities having a stowage factor of less
than 40 are known as deadweight cargo; those of
40 or more as measurement cargo." [2]

These stowage factors were obtained from individual shipping lines
and from the three publications in the field. [3] For measurement
cargo the measurement ton specification 40 cubic feet (sometimes
50 cubic feet on imports from Singapore) or 1 cubic meter(about 35.3
cubic feet on imports from continental Europe) was divided into the
rate to obtain the rate for one cubic foot of cargo. Then the
stowage factor (cubic feet occupied by a long ton) was divided by
22.4 to obtain the number of cubic feet per hundredweight. The
multiplication of the rate per cubic foot and the number of cubic
feet per hundredweight gives the rate per hundredweight for measure-
ment cargo. [4]

COMPONENTS OF THE TOTAL RATES USED IN THE STUDY

D-17 The total rate, expressed in cents per hundredweight, consists
of a variety of component parts which require some explanation prior
to presentation of the data. As is generally accepted, the subject of
freight rates is a detailed and complex matter.

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[2] Bross, Steward R. Ocean Shipping, Cornell Maritime Press,
Camoridge, Maryland, 1956, p. 149.

[3] Stowage Factors for all kinds of merchandise, compiled by
Captain O. Stahlbaum and W. Moth, Verlag Okis-Hamburg.

Stowage- The Properties and Stowage of Cargoes by Captain
R. F. Thomas, Revised by Captain O. O. Thomas, Brown, Son &
Ferguson, Ltd, Nautical Publishers, 52 Darnby Street; Glasgow:
Sixth Edition, 1968.

Modern Ship Stowage by Joseph Leeming, Edward W. Sweetman
Company, New York, 1968.

[4] $\dfrac{\text{Ocean Rate (Q)}}{\text{Measurement ton specification (40 cubic feet)(M)}}$ = Rate per cubic foot(R)

i.e. $\dfrac{Q}{M}$ = R

$\dfrac{\text{Stowage Factor (cubic space per long ton)(S)}}{\text{22.4 (\# of c.w.t. in long ton) (N)}}$ = Cubic feet occupied by
a hundredweight(C)

i.e. $\dfrac{S}{N}$ = C

Rate per cubic foot(R) x cubic feet occupied by a hundredweight(C)
= Rate per hundredweight for measurement cargo(R')

i.e. R x C = R'

D-18 <u>Rail and Truck Rates</u>. The rail and truck rates are published in the tariffs under class or commodity rate structures. Where a considerable volume of traffic moves from one specific point to another, a commodity rate, usually at a level lower than class rates, will be posted in the tariffs. A rule of thumb is that approximately 85 percent of all rail traffic moves under commodity rates. The commodity rate will also vary with the volume of the movement. A specific minimum weight will be required, and the rate will vary inversely with additional volume for the movement. Multi-car rates are common these days, and in some instances even a unit train rate might be applicable. If a commodity rate is not posted then the class rate structure will prevail. To compound the issue further, in some cases export-import rates will prevail for movements to coastal ports, whereas the domestic rate will apply to Great Lakes ports. In every case in applying the rates in this study, the most favorable position was accorded to each port, which would infer that shipments were made under the lowest possible rate structure, thus reflecting the best competitive position for each port. In the rail and truck tariffs, under special circumstances, special charges are listed for some commodities. They are referred to as ancillary or arbitrary charges, and in instances where they were listed, they have been added to the line haul rates and included in the overall calculation.

D-19 <u>Barge Traffic</u>. The movement of bulk commodities by barge to the port of New Orleans is extremely competitive. Selected barge rates have been obtained and included in the study data. Generally the movement will apply to grains, and the rate shown in the data will cover a combination truck and barge movement.

D-20 <u>Deep-Water Rates</u>. The international portion of the movement is covered by an ocean rate or a Great Lakes rate. These are on file as public information with the Federal Maritime Commission or are listed as open rates subject to negotiation. With respect to water rates, it is the practice to charge on either a weight or measurement basis of usually a long ton or 40 cubic feet at the discretion of the carrier, whichever yields the greatest revenue to the carrier. Determination to levy either a weight or measurement charge is made in light of the commodity's assigned stowage factor. A commodity with a stowage factor in excess of 40 cubic feet will usually be charged as measurement cargo, while stowage factors less than 40 cubic feet take a weight classification. In this study all measurement cargo rates have been reduced to a hundredweight basis as previously described.

D-21 **Port Charges and Seaway Tolls.** **A wharfage charge is levied at** most ports against the cargo. Wharfage is a charge assessed against merchandise that moves over port commission facilities. The terms terminal and transfer charges are used more generally on the Great Lakes. The ports are not uniform in the assessment of those charges. Such charges were only considered applicable when directly paid by the shipper. Where the carrier absorbed these charges, for example, West Coast Overland Common Point (OCP) freight, they were not considered as part of the rate. These charges are stated in the port handbooks and tariff sheets, and in this study the appropriate figure has been added to the total rate.

The final component that has been included in the overall rate for each commodity is the charge for the Seaway tolls. Great Lakes traffic must pay a toll for transiting the system, which is levied by the short ton on both general and bulk cargo. The fee, 90 cents per ton for general cargo and 40 cents per ton for bulk cargo, is passed on to the shipper and the appropriate charge, therefore, has been added on a hundredweight basis. At this time U. S. and Canadian currency differentials were not considered.

APPLICATION OF FREIGHT RATE ADVANTAGE.

D-22 The data were then analyzed to determine which port held an existing advantage in the movement of an individual commodity to or from domestic, Canadian, and overseas areas. The freight rate advantage of commodities actually moving from Great Lakes ports was weighted on the basis of interior points of origin or destination and overseas world area and port. In this way a value for a freight rate advantage was expressed for each commodity movement through the Welland Canal.

CONTAINERIZED CARGO

D-23 The full impact of the container revolution is currently being felt in the Great Lakes trade. In effect, the Seaway is going through a second shakedown period with respect to the movement of general cargo. At the present time,the volatility of the situation is such that a statistical analysis is not practical because of the lack of public time-series data. Therefore,in order to develop a meaningful body of data,it was felt that an interview survey would be the most appropriate method for researching the problem.

Briefly stated, the problem facing the Great Lakes ports calls for either development of a program to compete in this trade, or a policy to forego the possibility of competition and adjust to a new equilibrium position with respect to a share of the nation's commodity movement. The liabilities of the Seaway in the container trade, in part, result from the physical limitations imposed by the Seaway's structure, and the characteristics of vessel movements within the system. Thus,the new, full-sized,container vessels,capable of high speeds and quick turnarounds, cannot be used in the trade. As an alternative to employment of full-sized container ships,the feeder ship concept has evolved. At the present time,the Manchester Liners is operating two new container feeder vessels between Chicago and Montreal. These vessels, 320 feet in length, carry 194 containers to Montreal for transfer **to a full-sized** container ship.

On the shoreside of the movement,the specialized port container facilities required for efficient low cost operation,have not been provided. Containers do move through the Great Lakes ports,but the port facilities are set up for break bulk 5 and inefficiencies result. At this writing,an integrated modern container capability is not available at any of the Great Lakes' major ports.

In addition,a very competitive container rail movement between Chicago, Detroit, and Halifax has been in operation for the past three years. Over this route,(Grand Trunk Western-Canadian National) containers may be loaded on rail cars at Chicago or Detroit and subsequently placed aboard container vessels at Halifax or Montreal. The rate for this service from Chicago is $1.86 per hundredweight to Montreal and $2.80 per hundredweight to Halifax for Freight All Kinds

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Units of general cargo (as opposed to specialty cargoes such as bulk items petroleum, grain, and coal) which are handled individually and not in containers.

(FAK) in containers averaging ten tons in weight. The service is available year round and representatives of the railroad have indicated that a winter traffic peak is evident. General cargo movements in the port hinterlands of Milwaukee, Chicago, Detroit, and Toledo are strongly affected by this service.

In February 1973, the Eastern Railroads posted very competitive container rates for movement between the Port of New York and Chicago and St. Louis. The rate on a 10 container movement, Chicago to New York is $265.00 per container, $260.00 per container on a 50 container movement, and $255.00 per container on a 60 container movement. The 50 container movement would average $1.30 per hundredweight based on an average loading of ten tons per container. The direct impact of this service will be felt at Milwaukee, Chicago, Toledo and Cleveland.

D-24 **Interview Survey.** Individual interviews were conducted with a number of persons directly concerned with the container movement. Port operators, state economic development personnel, university researchers, ships' agents, and railroad agents were contacted. In some instances, requests for information were not responded to on the basis of proprietary rights. Based on the interviews, the container movement, export and import, through the ports listed below totaled 19,300. Actual figures for the rail movement of containers over the Chicago-Halifax route were not available, but an approximate total of 10,000 to 12,000 annually seems to be a realistic figure. This would place the figure for this part of the container traffic generated in the

TABLE D-33

1972 Container Traffic at Selected Great Lakes Ports[6]

Chicago	10,000
Detroit	4,000
Milwaukee	2,300
Cleveland	2,000
Toledo	1,000
	19,300

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[6] Based on interviews with port personnel regarding number of containers carrying cargo in both import and export trade.

Great Lakes hinterland at 30,000 containers. The containers generated in the midwest and shipped via the East, Gulf, and West Coasts are not included in this total. Using a conservative average figure of 10 tons per container, the total tonnage would fall in the range of 300,000 tons.

In summary, the interviews brought forth a diversified set of views regarding the traffic patterns. The rail representatives felt the service provided over the Chicago-Halifax route was very successful and well received by the shipper. The fact that year-round service was available was cited as an important advantage. The evidence of the winter peak in traffic indicates the service is very competitive.

The port operators expressed the view that they presently were at a competitive disadvantage because of the lack of proper port facilities. Yet a significant volume of container traffic currently moves, and at Chicago the volume increased 25 per cent in 1972.[7]   Elsewhere the indication was that container traffic volumes had reached a static level. Evidently, the situation from the port operators' viewpoint will not change, unless integrated container handling facilities can be provided.

D-25 Feeder Ship Operation. The Manchester Liners currently operates two container ships in the Lakes offering service between Chicago and Montreal. The service has been successful, but it has been inhibited during the last two seasons by strikes either at Montreal or in the United Kingdom. The agents for the company were optimistic but pointed out that the ship owners have made a considerable capital investment, and it is now up to the ports to modernize the shoreside operation if the true economies of containerization are to be realized.

D-26 Great Lakes and Coastal Ocean Rates for Containerized Cargo. A comparison of selected ocean rates on a hundredweight basis for containerized cargo show the Great Lakes to be competitive on the basis of the ocean rate. On other commodities, the negative net differential is more than   the savings on the inland rail haul, if this difference is less than $1.00. The Eastern Railroads (FAK) container train rates to/and from Chicago and New York would average about $1.30 a hundredweight. The special charges applicable to Great Lakes general cargo including wharfage, terminal, transfer, and seaway tolls range from $.10 to $.40 a hundredweight. These charges are usually absorbed by the port authority or the transportation company on coastal cargoes. Therefore, either a positive differential, or a negative differential of less than $1.00, would indicate transportation rate saving by using the Great Lakes ports.

[7] 8,000 containers in 1971 and 10,000 containers in 1972.

TABLE D-34

Transportation Ocean Rate Differential for Containerized
Cargo between Great Lakes Ports and Coastal Ports

Export Movements

Commodity	Foreign Port	U. S. Port	Rate Per CWT
Meat Products (Bacon)	Oslo, Malmo	New York	$5.05
Dried or salted not	Oslo, Malmo	Milwaukee	2.68
requiring refrigeration		Net Great Lakes Differential	+ $2.37
Soybean Meal (In Bags)	Japanese Ports	Seattle	$1.96
	Japanese Ports	Chicago	2.16
		Net Great Lakes Differential	- $ .20
Auto Parts (Access)	Rotterdam	New York	$3.73
	Rotterdam	Detroit	3.55
		Net Great Lakes Differential	+ $ .18
Office Machines	Rotterdam	New York	$4.88
(Calculators)	Rotterdam	Toledo	6.86
		Net Great Lakes Differential	- $1.98
Electric Motors	Rotterdam	New York	$6.51
	Rotterdam	Chicago	5.97
		Net Great Lakes Differential	+ .54
Construction Equip.	Japanese Ports	San Francisco	$11.36
Roadbuilding Graders	Japanese Ports	Chicago	14.15
(Boxed)		Net Great Lakes Differential	-$ 2.79
Machine Tools (Lathes)	London	New York	$7.88
	London	Toledo	7.44
		Net Great Lakes Differential	+$ .44
Machine Tools (Lathes)	Rotterdam	New York	$6.59
	Rotterdam	Toledo	6.07
		Net Great Lakes Differential	+ $ .52

Table D-34   Continued

Transportation Ocean Rate Differential for Containerized
Cargo between Great Lakes Ports and Coastal Ports

Import Movements

Commodity	Foreign Port	U. S. Port	Rate Per CWT
Canned Goods (Fish)	Oslo, Malmo	New York	$3.80
	Oslo, Malmo	Chicago	2.38
	Net Great Lakes Differential		+ $1.42
Cooking & Kitchen Utensils Cutlery	Oslo, Malmo	New York	$7.02
	Oslo, Malmo	Chicago	5.50
	Net Great Lakes Differential		+ $1.52
Auto Parts (Access)	Japanese Ports	New York	$7.44
	Japanese Ports	Chicago	5.67
	Net Great Lakes Differential		+ $1.77
Office Machines (Calculators)	Rotterdam	New York	$3.70
	Rotterdam	Chicago	4.05
	Net Great Lakes Differential		− $ .35
Electric Motors	Oslo, Malmo	New York	$5.71
	Oslo, Malmo	Chicago	5.43
	Net Great Lakes Differential		+ $ .28
Farm Tractors (Wheeled)	Rotterdam	Baltimore	$6.81
	Rotterdam	Detroit	5.36
	Net Great Lakes Differential		+ $1.45
Grinding Machines	Rotterdam	Philadelphia	$6.63
	Rotterdam	Cleveland	4.45
	Net Great Lakes Differential		+ $2.18
Hand Tools (Saws)	Oslo, Malmo	New York	$7.99
	Oslo, Malmo	Chicago	8.68
	Net Great Lakes Differential		− $ .69
Ceramic Tile	Japanese Ports	New York	$2.40
	Japanese Ports	Chicago	2.50
	Net Great Lakes Differential		− $ .10
China Householdware	Oslo, Malmo	New York	$3.11
	Oslo, Malmo	Chicago	4.12
	Net Great Lakes Differential		− $ .99
Sewing Machines	Japanese Ports	San Francisco	$8.58
	Japanese Ports	Chicago	11.86
	Net Great Lakes Differential		− $ 3.28

Transportation Ocean Rate Differential for Containerized
Cargo between Great Lakes Ports and Coastal Ports

Import Movements

Commodity	Foreign Port	U. S. Port	Rate per CWT
Sporting Goods	Oslo, Malmo	New York	$ 8.04
	Oslo, Malmo	Chicago	11.98
	Net Great Lakes Differential		$ -3.94
Sporting Goods	Japanese Ports	San Francisco	$ 8.22
	Japanese Ports	Chicago	12.23
	Net Great Lakes Differential		- $ 4.01
Motorcycles	Stockholm	New York	$ 6.56
	Stockholm	Chicago	10.07
	Net Great Lakes Differential		- $ 3.51
Steel Plate	Rotterdam	Philadelphia	$ 1.52
	Rotterdam	Detroit	1.64
	Net Great Lakes Differential		- $ .12
Steel Wire	Rotterdam	New York	$ 1.99
	Rotterdam	Detroit	2.25
	Net Great Lakes Differential		- $ .26

SUMMARY RATE SHEETS SHOWING LEAST COST ALTERNATIVE.

D-27 Detailed rates from origin/destination points through alternative Great Lakes or Coastal ports to overseas trading areas are shown in a separate document 8 for this study. These summary rate sheets include the forty-one commodities considered representative of the traffic shipped through the Welland Canal for domestic, Canadian, and overseas markets. First the bulk commodities including grains, coal, petroleum products, and iron ore; and secondly general cargo,9 including food and kindred products, chemicals, iron and steel products, machinery, transportation equipment, and other manufacturing are discussed.

Weighted savings per ton by commodity subgroup for cargo transiting on the Lake Erie-Lake Ontario Waterway Over the Least Cost Alternative is shown on Table D-35. The number of alternative origin-destination points and number of inland and ocean rates are also provided.

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Intermodal Domestic and Overseas Waterborne Rate Analysis for Great Lakes Area Commerce supplementary document for Lake Erie-Lake Ontario Waterway Economic Benefit Study.

9 U. S. Department of Commerce, Maritime Administration, _Essential United States Foreign Trade Routes_, Washington, D. C. U. S. Government Printing Office, December 1969, p. 78. "Dry Cargo-General - Miscellaneous goods packed in boxes, bags, bales, barrels, containers, crates, drums, unboxed or uncrated, accepted and delivered by mark and count."

Table D-35

Average Savings Per Ton For Cargo Transiting On
Lake Erie-Lake Ontario Waterway Over Least Cost Alternative

Commodity Sub Groups	Alternative Origin/Destination Points Utilized in Rate Comparisons					Weighted Savings Per Ton
	Inland Points	U.S.Great Lakes & Coastal Ports	U.S.Great Lakes, Canadian & Overseas Ports	Inland Rates*	Ocean Rates**	
GRAINS:	17	14	16	67	82	1.81
Corn	8	5	5	32	28	0.81
Soybeans	6	4	4	18	18	1.14
Wheat	3	5	7	17	36	3.21
COAL	-	3	6	6	6	8.66
PETROLEUM PRODUCTS	-	4	5	9	9	6.72
CEMENT, STONE, SAND & GRAVEL	-	11	11	14	14	3.40
IRON ORE	-	15	2	15	15	2.41
OTHER BULK	17	43	35	102	117	4.12
GENERAL CARGO:	223	164	134	1,054	452	18.81
Iron & Steel Products	23	15	7	107	33	18.50
Chemicals	13	12	12	61	40	28.36
Food	49	43	39	263	149	15.37
Transportation Equipment	33	17	17	131	43	53.52
Machinery	74	49	41	357	134	33.18
Other Manufacturing	31	28	18	135	53	19.21
TOTAL ALL GROUPS	257	254	209	1,267	695	7.27

* Includes rail, truck and combination truck-barge.
** Includes overseas, Canadian and domestic. For overseas rates both direct ocean and laker ocean combinations were considered.

SECTION III - SIMULATION

INTRODUCTION

D-28   This Appendix summarizes four major processes, as follows:

1.   establish the expected limits of service of the existing
      Welland Canal;

2.   establish the expected incremental increase in service
      potential of the existing Welland Canal under assumptions
      of improved locking procedures and an improved traffic
      control system;

3.   determine the expected performance of a combined Welland-
      Niagara system with configuration alternatives of four,
      five,and six locks in series in the Niagara Canal in
      combination with the existing Welland Canal;

4.   examine the expected performance of a replacement for the
      Welland Canal,consisting of a series of four super locks
      plus a guard lock towards the mouth of Lake Erie.

These configurations were subjected to current and anticipated levels of
traffic, fleet composition, ship size, and operating procedures. The
primary measure of system performance was system transit time. This
variable reflects both the service levels provided by system facilities
and any delays that occur due to congestion. In addition, measures of
lock utilization, lock processing time, and time spent in queues were
taken,so that the system response could be stated in terms of delays
due to congestion and lock utilization. However, no analysis of the
effects of delays and system congestion upon demand was undertaken.
Hence, the emphasis of the study was placed upon determining what

configurations of navigation facilities are required to meet the prospective transportation demand and enable the network to function effectively as a system.

D-29 System Design Alternatives

Simulation of the existing Welland Canal established the calibration values for the model's parameters. Recent traffic data for the Welland Canal were used to establish state-dependent relationships between vessel transit time and the number of ships in the canal. The canal was simulated using input data, representative of the conditions corresponding to those for which the traffic data were compiled. The capacity of the existing canal was established by subjecting it to waterway transport demand through the year 2030.

It has been reported that improvements in locking operations and the installation of a traffic control system in the Welland Canal have led to an increase greater than 33 percent in the potential number of lockages per day [1] The study cited also states that on the average, 1 minute saved per lock cycle [2] saves 1 hour in round-trip transit time for the vessels. An earlier report stated that a lock cycle time of 70 minutes might eventually be achieved (2). The conclusions reached in these two reports suggest that the already improved locking time might be further reduced by an additional 2 minutes, resulting in a further improvement in round-trip transit time on the order of 2 hours.

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[1] Numbers in parentheses refer to reference for Section III, Attachment D-6

[2] A lock cycle is the time needed for a lock to move one vessel down and one vessel up. This includes all the ship movements and lock operation from the time a boat is instructed to enter a lock to the time when the lock is ready to receive the next lockage in the same direction.

The effects of nonstructural improvements on the Welland Canal can be inferred under the assumption that the optimization of vessel scheduling and locking procedures can, in fact, lead to improvements in vessel transit time on the order of those stated above. Simulation runs for future time periods using inputs revised to incorporate these efficiencies, were made in order to ascertain the capacity of an "improved" Welland Canal.

For the purposes of this study, the Welland Canal was modeled as a set of six entities, corresponding with the traffic data that were compiled, where the operations within each entity were inferred, rather than specifically modeled. Transit time through the system depended on the number of ships in the canal and was calibrated on the basis of empirical data. The effects of additional nonstructural improvements to the canal were determined by simulation experiments as described above.

Four different structural alternatives for the Welland Canal were studied. Three of these alternatives consisted of two parallel channels in a combined Welland-Niagara system. The performance of this system was measured for configurations of four, five, and six locks in series in the Niagara Canal in combination with the existing eight-lock Welland. The simulation used transit time data, representative of the future improved operations at the Welland and performance data for the Niagara based on expected service and transit times similar to those experienced at the Welland Canal.

The fourth structural configuration involves a unilateral Canadian alternative to the Welland where the existing system would be replaced by a series of five locks[3] of greater lift and 1200' x 110' dimensions. This configuration was simulated as a single channel using the same predicted service and transit times as for the Niagara alternative.

D-30 Methodology

The basic methodology for the Welland Canal simulation experiments entailed the division of traffic between parallel facilities. This factor dictated that a channel assignment mechanism be incorporated in the modeling system. The following model specification was formulated. (3)

1. Canal Operating Rule: all ships may use either existing or new facilities when physically possible; ships too large to use the existing locks must be assigned to the large new locks.

2. Lock Operating Rules: ships queuing on both sides of a lock should be serviced alternatively. A recycle "lookahead" capability should be included such that, there being no queues at a lock, the lock water level should be adjusted to accept the second of two ships traveling in the same direction, prior to its arrival at the lock, time permitting.

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3 Includes a guard lock.

3. Reach Operating Rule: ships should be allowed to catch up with, or fall further behind, a preceding ship, but should not be allowed to pass a preceding ship in a canal reach.

4. Assignment Decision Rule: ships should be assigned between parallel facilities on the basis of the least expected transit time.

The model formulation has been extensively documented (4) but a brief mention of the assignment decision mechanism is made here since it has a significant bearing on the methodology of the simulation experiments.

The assignment decision involves the simulation of each parallel branch separately, using a special option embedded in the simulation model to produce an "experience data base" (EDB). These experience data bases are then statistically analyzed to select the most significant variables and to establish coefficient values for use in a set of transit time estimating functions for each branch. The coefficient values and variable identities for use in each branch estimating equation are specified by the user. With these calibrated functions available, simulation of the system of parallel canals can be performed. When a ship arrives at a channel choice point, the channel assignment is based on the least expected transit time.

This empirical approach was adopted because it was found that an analytical approach to the determination of expected transit time through a multiple lock and reach canal was extremely complex and was

intractable. It is, therefore, postulated that a statistical relationship should exist between the conditions existing in a canal when a ship arrives at the assignment decision point and the time that will be required to subsequently travel through that canal. By performing a simulation (called an EDB run) of a given channel configuration (i.e., a specific canal branch), it is possible to develop an experience data base which includes prior canal conditions for each ship arrival and subsequent ship transit time. This data base may then be analyzed, using a standard statistical program, to establish the required relationships between expected transit time and canal conditions. Separate relationships for each of the Welland-Niagara configurations, differentiated by direction of travel, were developed.

Thus, the EDB concept requiring preliminary simulation runs for the formulation of the expected transit time functions, constitutes the first phase of the methodology. The actual simulation of the network configurations, using these expected transit time functions for various input factors through different levels of transport demand forms the second phase. An actual simulation (called an EVENT LOG run) generates a log of each event occurrence during simulation, and this event log is usually placed on an external output device such as a magnetic tape for permanent storage. It is this event log which is used during the third phase of the methodology.

Because of the complexity and sheer volume of the simulation model's logic structures, the burden of statistical evaluation was shifted to a post-simulation phase. Thus, the third phase consists of an event log post-processor which utilizes the event log generated during the second phase to summarize significant statistical data. The task of this event log processor is conceptually simple since it merely reads in the event log as input data and translates it into periodic (thereby providing intermediate snapshots) statistical summaries. The processor, however, also includes options for determining such simulation specifics as transient time and autocorrelation in data.

The distinction between "transient state" and "steady state" is extremely relevant for simulation studies. A transient state is defined as a condition in which operating characteristics of a system are changing with time in irregular fashion; and, conversely, a steady state means an environment in which system operating characteristics are not time varying. In the simulation context, a transient state usually exists at the start of a simulation run when the system is in some initial state. During the course of the simulation, the system eventually reaches a steady state as it accepts more entities, although, under high utilization, the system may depart from steady state.

Thus, the amount of simulation time required to reach this steady state (called warm-up time) is of critical importance to the analyst as he will normally want to make decisions based only on steady state performance measures. The warm-up time may be determined in a number of ways (5). The event log processor uses a procedure that examines the behavior of delays at locks through spectral analysis.

The spectral analysis methodology was originally necessitated by the presence of autocorrelation in simulation data. In most simulations generating time series data, there is a certain degree of dependence on past events which violates a common statistical requirement that the data be independent. A spectral analysis approach, however, can be used in such cases to measure autocorrelation and take it into account in the subsequent analysis. This approach has been documented elsewhere (6); hence, no description is given here. The use of this approach in the Welland-Niagara studies led to the choice of 5000 minutes as the warm-up time and 30,000 minutes as the total simulation time.

D-31 Assumptions

All simulation experiments were conducted under the following assumptions.

1. The system never breaks down.

2. All locks operate under the "SOQA" (Serve Opposing Queues Alternatively) rule, where ships queuing on both sides of

a lock will be served alternately, reverting to "First Come First Served" only when one queue becomes empty.

3. The channel-choice decision rule for parallel branches is based on least expected transit time.

4. There are no double, tandem, or combination lockages.

5. There is no priority service given to any ship.

6. Time of day does not affect traffic levels (nor day of week, nor month of season).

7. Locks operate 24 hours per day, 7 days per week.

8. There will be no passing in any reach.

9. Reach transit time will not be a function of ship size or ship direction of travel.

10. Statistics are gathered under steady state conditions.

11. Arrivals are random at the endpoints of the canal in Lake Erie and Lake Ontario.

INPUT DATA BASE

D-32 Data Sources

The data source for the Welland Canal was the St. Lawrence Seaway Authority which supplied "Welland Canal Vessel Transit Analysis Daily Details" for the months of April, June, August, and October, 1971. The data for the months of April and October were influenced by seasonality effects, but preliminary examinations indicated that August data would adequately serve the purposes of this study.

The data sources for the Niagara Canal were the Corps of Engineers, Buffalo District and North Central Division. The data developed by the Corps consisted of system configuration parameters, transit time distributions for locks and reaches, and finally the fleet data for the Welland-Niagara studies.

D-33 Data Description

A complete description of the data used in this study is given in later portions of this Appendix. This portion merely provides some of the salient features of the input data.

a.   Fleet Data

The fleet data consisted of actual average daily transits at the Welland Canal for 1970 and projected average daily transits by decade from 1980 through 2030. As shown in Table D-36, traffic was projected for both United States and Canadian movements between Lake Erie and Lake Ontario.

Existing and Projected Traffic between Lake Erie and Lake Ontario

UNITED STATES TRAFFIC
Total U. S. Waterborne Commerce Between Lake Erie
and Lake Ontario - 1960-71, Actual,
and 1980, 1990, 2015 and 2020 Projected

1960-65	-	31,748
1966-70	-	44,444
1971	-	44,150
1980	-	53,400
1990	-	63,600
2015	-	89,500
2040	-	115,000

CANADIAN TRAFFIC

Total Canadian [4] Waterborne Commerce Between
Lake Erie and Lake Ontario 1960-71 Actual,
and 1980, 1990, 2015 and 2040 Projected

1960-65	-	10,399
1966-70	-	12,866
1971	-	18,759
1980	-	24,600
1990	-	30,400
2015	-	42,500
2040	-	55,200

TOTAL U. S. AND CANADIAN TRAFFIC

Total U. S. and Canadian Waterborne Traffic Between
Lake Erie and Lake Ontario, 1960-71 Actual,
and 1980, 1990, 2015 and 2040 Projected

	United States	Canada	Total
1960-65	31,748	10,399	42,147
1966-70	44,444	12,866	57,310
1971	44,150	18,759	62,909
1980	53,400	24,600	78,000
1990	63,600	30,400	94,000
2015	89,500	42,500	132,000
2040	115,000	55,000	170,000

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[4] Includes Canada - Canada and Canada-Overseas; Canada-U. S. Traffic
include with U. S. Totals

The projected traffic is considered reasonable with only moderate growth rates reflected in the 1980-2040 period compared to the accelerated growth in Lake Erie-Lake Ontario traffic in the 1958-1972 period. A complete discussion of traffic by commodity group is contained in **Section I of this appendix.**

Associated with the traffic projections was a fleet composition factor representing the estimated trend towards larger vessel size. Fleet data consisted of three vessel classes, delineated by length of vessel as follows:

Class I   :   1 -   399 feet

Class II :   400 -   730 feet

Class III: 731 - 1150 feet

A description of the projected fleet composition (percentage distribution by class) for the years 1970 through 2030 is given in Table **D-37** It is noted that Class III is comprised of vessels too large to be processed through the existing Welland Canal and is representative of a fleet/transit demand situation when the vessels in Class III would utilize the Lake Erie-Lake Ontario/St. Lawrence Seaway facilities if such facilities were physically compatible.

b.   Lock Data

The simulation model, herein referred to as NETSIM/SHIP (NETwork SIMulator of SHIP movements), [5] represents a lock operation in terms of nine elements as depicted in Figure D-2 and delineated in Table **D-38**

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[5] A complete description of the simulation model is given in Reference (1).

TABLE D-37 FLEET COMPOSITION-PERCENTAGE DISTRIBUTION BY CLASS[6]

	Class I (1'-399')	Class II (400'-730')	Class III (731'-1150')
1970	10.0	90.0	0.0
1980	8.0	87.0	5.0
1985	6.0	84.0	10.0
1990	5.0	80.0	15.0
1995	4.0	71.0	25.0
2000	3.0	62.0	35.0
2010	1.0	54.0	45.0
2020	1.0	44.0	55.0
2030	1.0	34.0	65.0

Note: Data for 1970 are actual, for the others are projected.

[6]Representative of fleet-transit demand for each period, i.e. vessel transit distribution that would occur if physical system would permit.
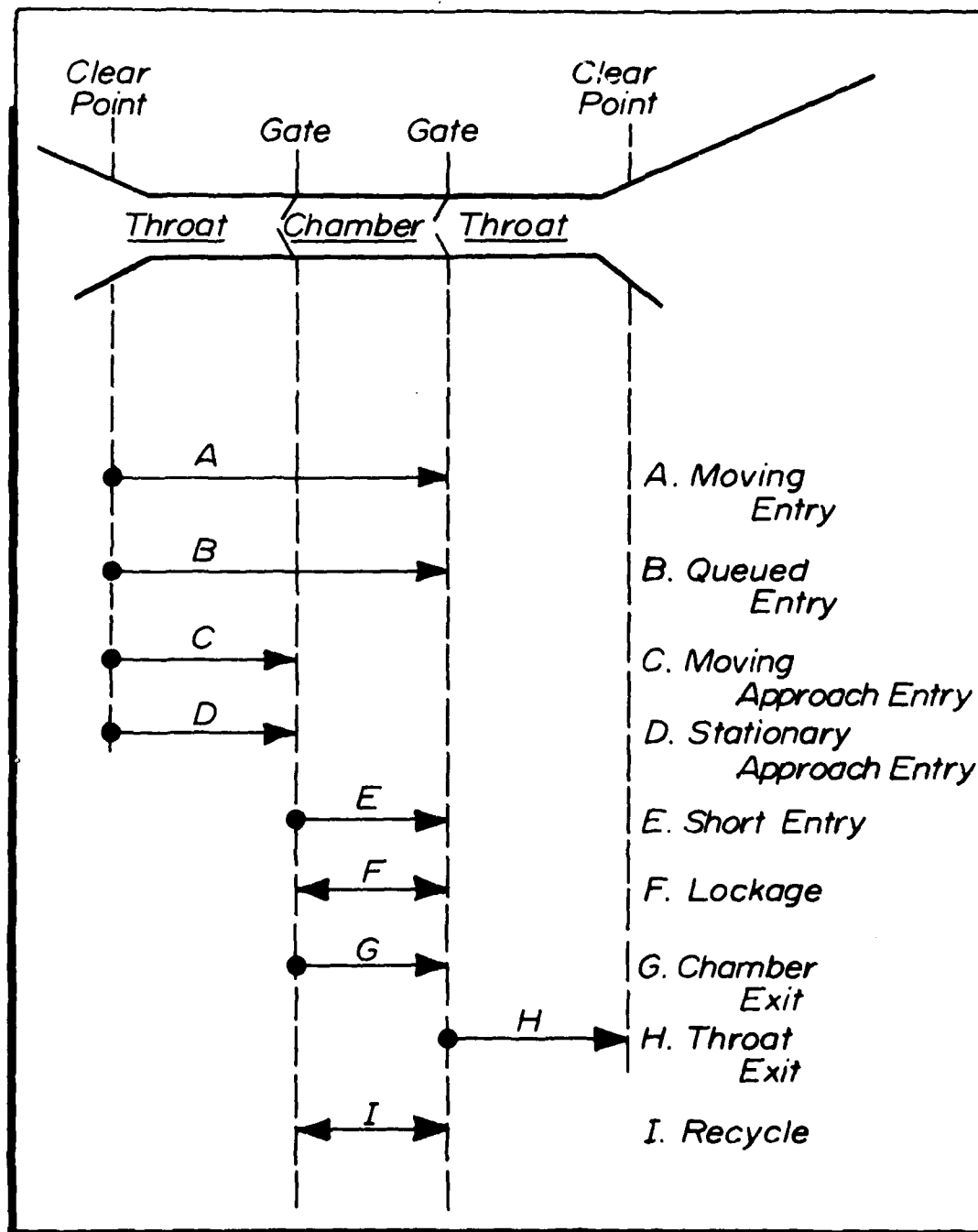
Figure D-2   Schematic of Simulated Locking Time Events

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TABLE D-38 DESCRIPTION OF LOCKING TIME EVENTS

EVENT NAME   DESCRIPTION

A. MOVING ENTRY   into the lock chamber from the Clear Point at
                             the end of the entry throat.
        Begins: when the bow of the ship passes the Clear Point.
        Ends: when the gates begin to close astern of the
                             ship.

B. QUEUED ENTRY   into the lock chamber from the head of the
                             queue adjacent to the Clear Point.
        Begins: when the gates are fully open and the chamber
                             is free.
        Ends.   when the gates begin to close astern of the
                             ship.

C. MOVING APPROACH
        ENTRY   from the Clear Point to a position in the entry
                             throat just clear of the entry gate.
        Begins: when the bow of the ship passes the Clear Point.
        Ends: when the ship comes to rest in the entry throat.

D. STATIONARY APPROACH
        ENTRY   from the head of the queue adjacent to the Clear
                             Point to a position in the entry throat just
                             clear of the entry gate.
        Begins: when the bow of the ship passes the Clear Point.
        Ends: when the ship comes to rest in the entry throat.

E. SHORT ENTRY   into the lock chamber from a stationary position
                             just clear of the entry gate in the entry
                             throat.
        Begins: when the gates are fully open and the chamber
                             is free.
        Ends: when the gates begin to close astern of the ship.

F. LOCKAGE   of a ship at rest in the chamber.
        Begins: when the entry gates begin to close astern of
                             the ship.
        Ends: when the exit gates are fully opened after the
                             change in water level.

G. CHAMBER EXIT   from chamber to position where the ship's stern
                             clears the exit gate.
        Begins: when the exit gates are fully opened after the
                             change in water level.
        Ends: when the ship's stern is clear of the exit gate.

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EVENT NAME   DESCRIPTION

H.   THROAT EXIT   from position where the ship's stern clears the
                                    exit gate to the Clear Point at the end of the
                                    exit throat.
     Begins: when the ship's stern is clear of the exit gate.
     Ends: when the stern of the ship passes the Clear
                                    Point.

I.   RECYCLE   of the water level with no ship in the chamber.
     Begins: when the gates begin to close.
     Ends: when the opposite gates are fully open to re-
                                    ceive an incoming ship.

Each of these nine elements can be described in the simulation model by either a frequency distribution or an average time of operation. The data for these elements by class size and direction of travel is shown in Table D-39 All the locks in the Niagara Canal of **four, five,** and six-lock configurations as well as the four-super-lock Welland configuration were of size 1200' x 110' and used these identical data.

c.   Welland Transit Data

The only major treatment of raw data occurred for the "Welland Canal Vessel Transit Analysis Daily Details" for the month of **August.** This treatment had two objectives.

The first objective was to obtain a transit time distribution for each of the Canal's six entities for calibration purposes. Figure D-3 provides a schematic description of the six entities representing the Welland Canal, and Table D-40 summarizes the corresponding transit data.

The second objective was the derivation of a transit time equation as a function of system conditions which would be used to predict the expected transit time through the canal during simulation. The results of this treatment are given in Attachment D -1. Note that the corresponding transit time equation for the proposed Niagara Canal had to be derived through an EDB simulation run; the results of which are also given in Attachment D -1. An EDB run was not necessary for the Welland Canal, however, since empirical data were available.

TABLE D-39 LOCK DATA FOR WELLAND-NIAGARA STUDIES

(Average Times of Operation in Minutes)

	Lock Elements	Direction	Class I	Class II	Class III
A.	MOVING ENTRY	Up	14	18	21
		Down	13	17	20
B.	QUEUED ENTRY	Up	17	21	24
		Down	16	20	23
C.	MOVING APPROACH ENTRY	Up	8	11	13
		Down	7	10	12
D.	STATIONARY APPROACH ENTRY	Up	11	14	16
		Down	10	13	15
E.	SHORT ENTRY	Up	8	11	14
		Down	7	11	13
F.	LOCKAGE (PROCESS)	Up	8	8	9
		Down	8	8	9
G.	CHAMBER EXIT	Up	4	5	6
		Down	4	5	6
H.	THROAT EXIT	Up	3	4	4
		Down	3	4	4
I.	RECYCLE	Up	6	6	6
		Down	6	6	6
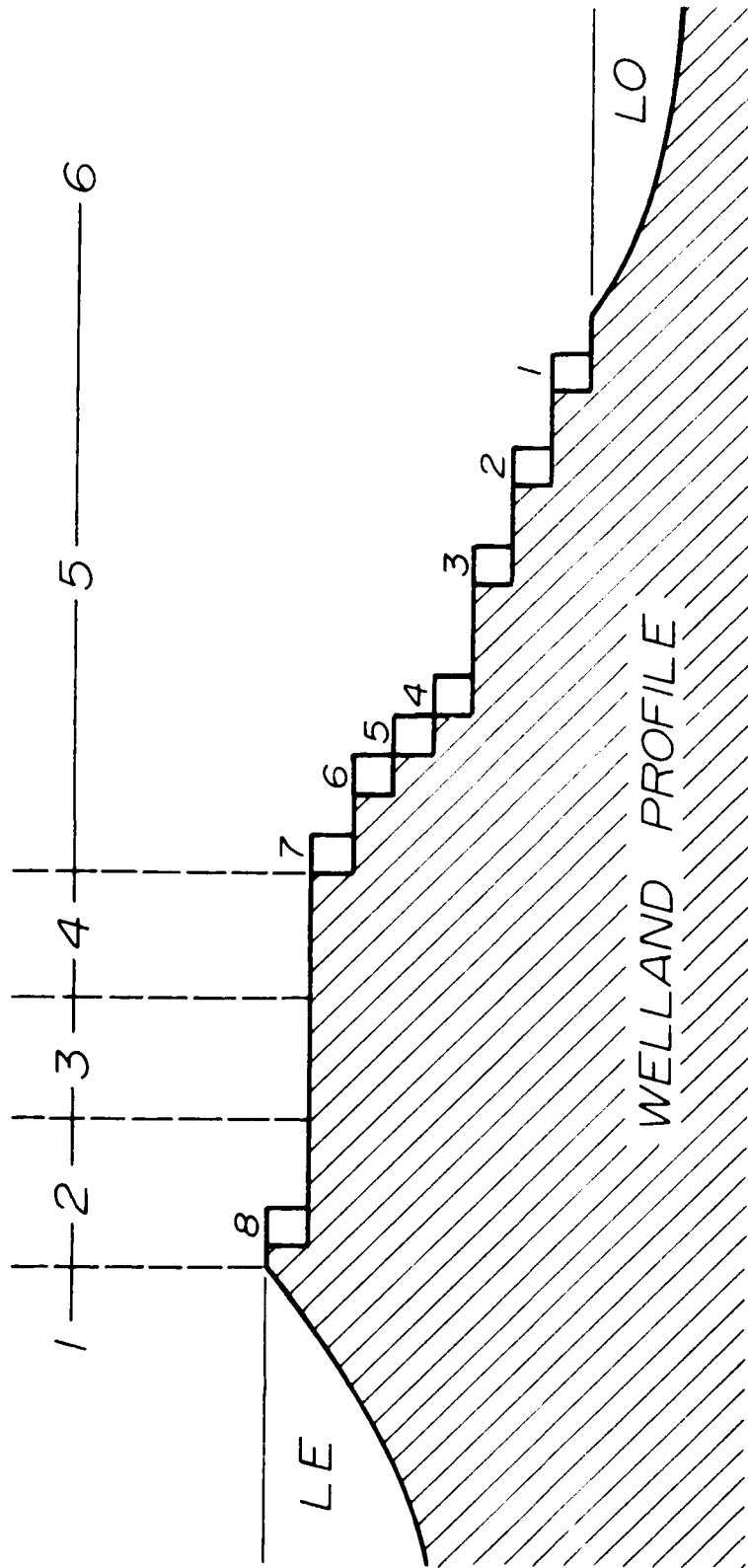
Figure D-3. Simulated Representation of the Welland Canal

TABLE D-40. TRANSIT DATA FOR WELLAND - AUGUST 1971

Explanation	Simulation Reach Identification Numbers	UPSTREAM		DOWNSTREAM	
		Mean (hours)	% of Total Transit Time	Mean (hours)	% of Total Transit Time
Downstream Waiting Area	2150	0	0	2.483677	19.66
Reach 4*	2200	1.643601	12.35	1.156160	9.15
Reach 3	2250	1.976400	14.85	1.948431	15.42
Reach 2	2300	1.012270	7.61	1.269250	10.05
Reach 1**	2350	6.158961	46.29	5.775386	45.72
Upstream Waiting Area	2400	2.513889	18.89	0	0
Total		13.305121	99.99	12.632904	100.00

*Reach 4 extends from Bridge 18 to Lock 8 (Guard Lock).

**Reach 1 extends from Lock 1 to Lock 7.

CALIBRATION

D-34   The simulation run for the existing Welland Canal network,
modeled as a set of six reaches under a 1971 traffic load, served
as the base run for subsequent analysis of various other configura-
tions. This simulation methodology did not use Monte Carlo sampling
from random probability distributions for a vessel's transit time,
but rather utilized an empirical transit time-system condition rela-
tionship obtained through regression.

Thus, at the moment of a vessel's entrance into the Welland
Canal, its expected canal transit time was computed as a function
of the existing system conditions. Transit through individual reaches
was subsequently accomplished through random sampling from prior
distributions whose means were empirically determined fractions of
the expected canal transit time.

Since the technique described above constitutes, in principle,
a projection of the empirical relationship rather than true Monte
Carlo simulation, it will be henceforth referred to as "ETT (empirical
transit time) simulation." The projection of this relationship is
valid for only finite deviations from the 1971 traffic load, in fact
only for the range of the empirical data from which the relationship
had been obtained. Since the traffic load for some of the future
periods in the analysis falls outside this range, queuing theory as
explained in Attachment D-2 of this appendix was used to supplement
ETT simulation.

The calibration run, then, consists of an ETT simulation of the existing Welland Canal under a 1971 traffic load. A fleet mix of 30 percent Class I and 70 percent Class II was used. Results of the simulation run, shown in Table D-41, are differentiated by direction and are given in both minutes and hours. Transit times through individual sections of the canal compare favorably with the empirical data (see Table D-40) The latter are understated by about 4 percent for downstream transit and by about 1.5 percent for upstream travel with an overall underestimation of about 2 percent.

TABLE D-41   SIMULATION TRANSIT DATA FOR THE EXISTING WELLAND

USING 1970 TRAFFIC DENSITY

Simulation Identification Number	2150	2200	2250	2300	2350	2400	Total	Average
	Upstream Waiting Area	Bridge 18 to Lock 8	Bridge 10 to Bridge 18	Lock 7 to Bridge 10	Lock 1 to Lock 7	Downstream Waiting Area		
UP	-	97	116.7	59.8	363.8	148.5	786	757
	(0)	(1.616)	(1.945)	(.997)	(6.06)	(2.475)	(13.1)	(12.617)
DOWN	143	66.5	112	73	332.4	-	727	
	(2.38)	(1.11)	(1.867)	(1.217)	(5.54)	(0)	(12.116)	

Average Transit Time (minutes)

NOTE: Conversion to hours appear in parentheses.

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WELLAND CANAL CAPACITY STUDIES

D-35 Capacity of the existing Welland Canal was derived for each of two conditions: (1) existing Welland with no further major improvements, and improved Welland with nonstructural improvements. A reasonable estimate of the capacity of the Welland Canal may be derived from a number of ways. Three techniques that were considered are: (1) Monte Carlo simulation, (2) analytical methods such as queuing theory and regression analysis, and (3) a qualitative appraisal based on the nominal capacities of individual locks in the Welland.

Although the results of Monte Carlo simulation models for waterway systems analysis have been applied favorably in other Corps studies, the sophisticated control system at Welland poses problems for such simulation. In particular, rules and procedures such as the priority rating for ships proceeding toward lock 7 over those which have passed it, the preferential treatment to faster ships if a gap develops in the traffic toward lock 7, special rules for heavy one-way traffic and for ships most susceptible to wind and fog are difficult to model. For these and other reasons, Monte Carlo simulation has not been employed in the Welland studies.

Discussions with the St. Lawrence Seaway Authority have indicated that a maximum of 40 lockages per day can be accomplished at the Welland locks. This accomplishment can only occur under conditions of favorable weather, of large queues (in the order of 10) on both sides, and of normal operation. Any deviations from these conditions such as fog or

an accident leads to a rapid increase in the queue. A more reasonable
level of capacity quoted is around 36 lockages per day or about 90 per-
cent of nominal capacity. Increasing the capacity in terms of vessels
per day or lockages per day is, however, only one measure of performance.
What matters most to shipping companies is the total canal travel time,
including both the time they wait to enter the canal and the actual canal
transit time itself. This total travel time could be increased even
though capacity in terms of lockages per day is increased. For example,
lock utilizations of the order given above require large queues on either
side of the lock, and hence it is necessary to have many vessels inside
the canal at any one time. Then, even though the input rate and output
rate from the canal were increased, the canal transit times associated
with this level of operation could also be extremely large.

The capacity of the Welland Canal may also be estimated by way of
analytical methods. The method employed in this study is the queuing
model.

D-36 **Results**
[7]

Given the arrival rate in terms of expected lockages per day
and the largest lock service time, the ratio of these two parameters
provides a measure of system capacity. When this ratio reaches one
or 100 percent, the system is said to have found its nominal capacity.

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[7] · This characterizes one of the assumptions of this study, viz., there
will be no tandem or multiple lockages. In reality, these constituted about
11 percent of the arrival rate in 1971, a decline from 20 percent in 1965.

Discussions with the St. Lawrence Seaway Authority revealed that lock 7, which is the bottleneck on the Welland Canal, had a lock cycle of 72 minutes or a single lockage time (including ship entry and exit) of 36 minutes. Solving for the arrival rate in terms of lockages per day needed to reach the nominal Welland Canal capacity, this figure turns out to be exactly 40 (lockages per day), which is consistent with the maximum lockage rate quoted by the St. Lawrence Seaway Authority.

In a similar manner the expected system capacity in percentage for each year of projected growth can be calculated, and these results are shown in Table D-42 These figures are lower than the lock utilizations that are currently realized because the effects of coordinating tandem and multiple lockages are not included. If the latter continue to develop in future traffic, the canal could saturate earlier than Table D-42 would indicate.

To draw inferences regarding Welland capacity, it is necessary to set forth a definition of capacity. (It is assumed here that the definition that is of interest would consider the transit time associated with some particular level of input traffic or lock utilization rather than the nominal capacity that has been referred to previously).

TABLE D-42   THE EXISTING WELLAND CANAL - CAPACITY SUMMARY

1971 - Actual and 1980-2030 - Projected Traffic

Year	Arrival Rate (Number of (Lockages per Day)	% of Nominal Capacity
1971	25.5	63.7
1980	27.4	68.5
1985	28.55	71.4
1990	29.7	74.2
1995	31.15	77.9
2000	32.6	81.5
2010	35.7	89.2
2020	39.8	99.5
2030	44.3	arrival rate greater than lock service rate

One can obtain some assistance on this point from the reference to
75 percent of nominal capacity in literature as representative of an
economical or practical level of capacity—[8] . If this criterion is
used to indicate capacity, it is met at or about 1990 under the traffic
level and operating associations used in this report.

In Figure D-4 , capacity is indicated in that portion of the curve
where the slope is changing rapidly. This indicates that further
traffic can be introduced into the canal; however, the delays associated
with such additional increases would rapidly accelerate. Further, the
traffic projections represent 29.7 lockages per day, which is the
seasonal daily average for the Welland Canal. Traffic during certain
periods of the season may be greater than these seasonal averages,
however.

The statement "Welland capacity is reached in 1990, therefore,
involves the following assumptions:

1. Capacity used in the above statement is 75 percent of the
    maximum theoretical capacity.

2. The traffic projections used are seasonal averages.

3. The traffic projections used are the number of lockages per
    day and not vessels per day.

[8]
    Santina, William J., and Wesler, George B., "Duplicate Locks for
Illinois Waterway," Journal of the Waterways and Harbors Division,
ASCE, Vol. 90, No. WW4, Proc. Paper 4118, Nov., 1964.
    Davis, J. P., "Tonnage Capacity of Locks, "Journal of the Waterways
and Harbors Division, ASCE, Vol. 95, No. WW2, Proc. Paper 6577,
May, 1969, pp. 201-213.
    Ferguson, H. A., Engel, H., and Blok, S.I.E., (Untitled), XXII Inter-
national Navigation Congress, Paris, 1969, Permanent International
Association of Navigation Congresses, Brussels, Belgium, Section 1,
Inland Navigation, Subject 4, pp. 97-114.
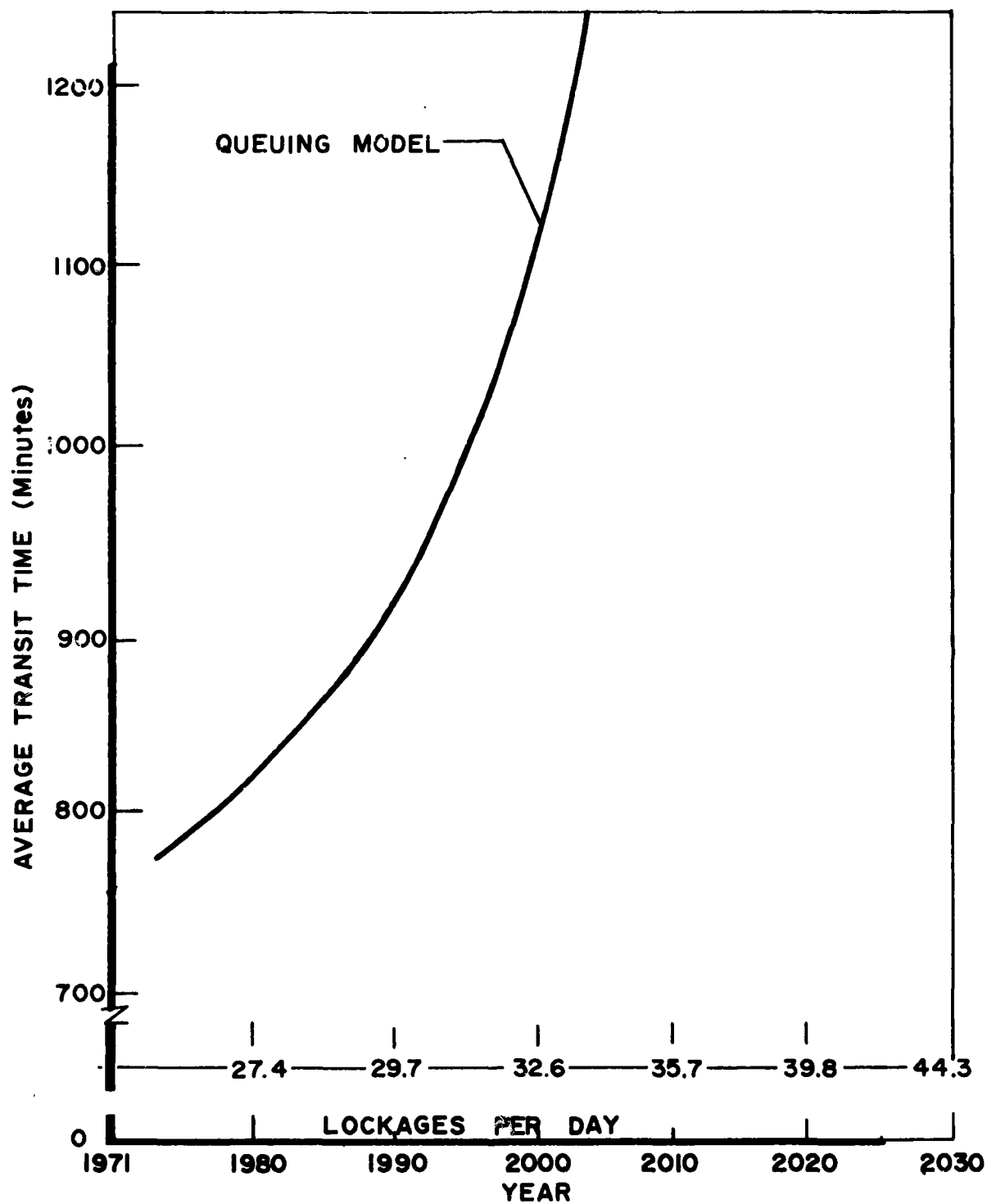
FIGURE D-4   Transit Time for the Existing Welland Canal

4. The effects of coordinating tandem and multiple lockages are not included.

5. Structural as well as nonstructural operations as in existence in 1971 are assumed to remain unchanged.

D-37 Capacity of the Improved Welland (Nonstructural)

In the simulation of this task, the effects of various non-structural improvements were assumed to have resulted in first, a reduction of the lock cycle from 72 minutes to 70 minutes; and second, the translation of this efficiency into a net transportation savings of 2 hours in round-trip transit time.

Thus, the simulation itself consisted of incorporating these efficiencies in the model's transit time distributions derived for each vessel when it arrives at the call-in-point and therefore, is again an extrapolation of a current empirical relationship to future demand. Hence, this technique suffers from the same shortcoming as the previous one and is valid only for finite deviations from current capacity.

Capacity is related to the input stream as shown in Table D-43. The capacity figures represent a ratio of the input rate to the lock service rate where the latter assumes a lock service time of 35 minutes per lockages. Nominal capacity for this system is 41 lockages per day, but using the criterion from the previous section, 75 percent of system capacity is reached at a vessel arrival rate of about 31 lockages per day and occurs about 1995. An estimate of the transit time associated with these levels of system utilization can be obtained from Figure D-5 This figure shows the queuing model results; the similarity of behavior between this and the preceding network is as expected.

TABLE D-43. THE WELLAND CANAL WITH NONSTRUCTURAL IMPROVEMENTS - CAPACITY SUMMARY

Year	Arrival Rate Lockages/day	% of Nominal Capacity %
1980	27.4	66.6
1985	28.55	69.4
1990	29.7	72.2
1995	31.15	75.7
2000	32.6	79.2
2010	35.7	86.8
2020	39.8	96.7
2030	44.3	arrival rate exceeds service rate
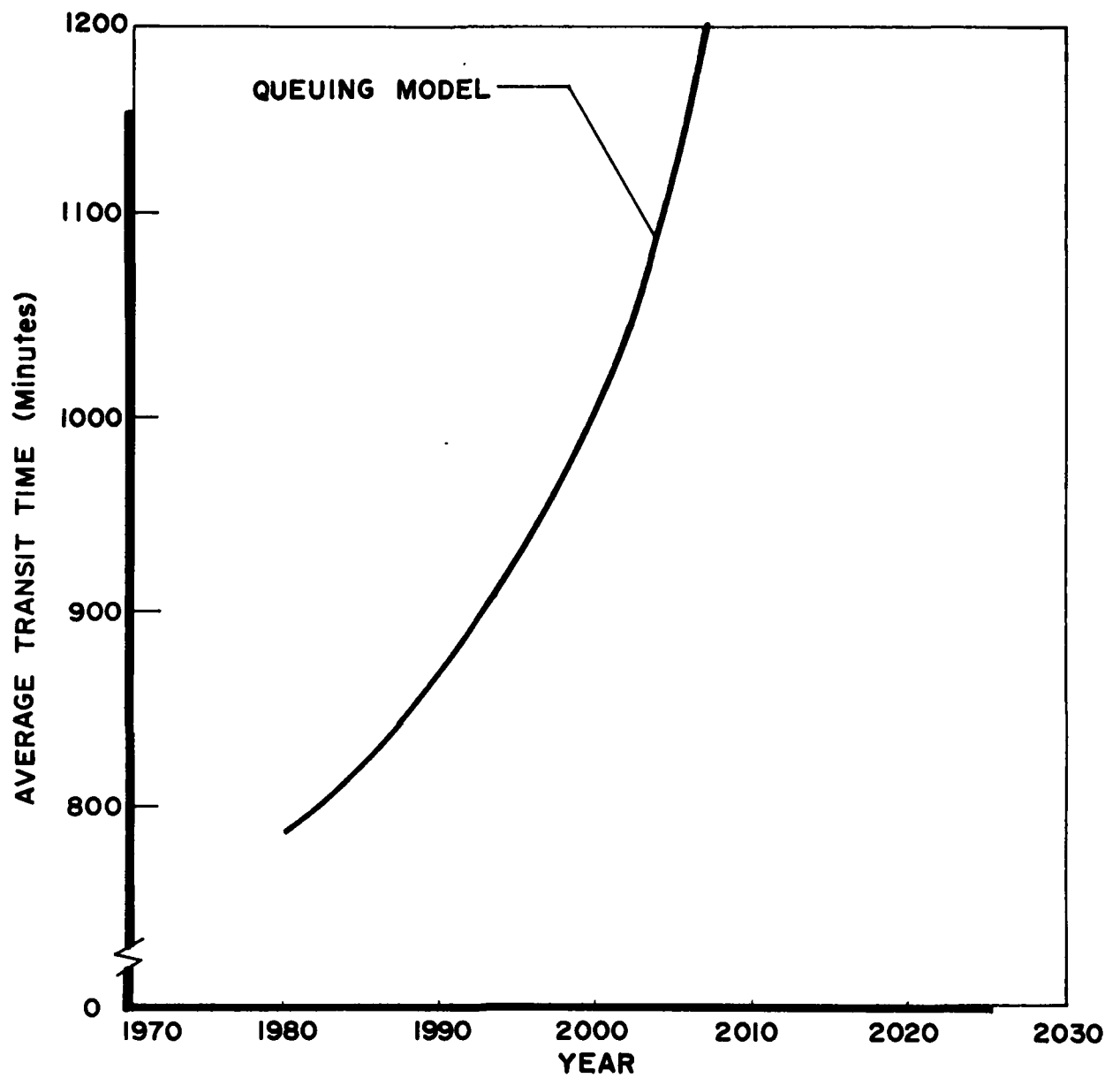
FIGURE D-5 Transit Time for the Improved (Nonstructural) Welland Canal

D-97

IMPACT OF THE NIAGARA CANAL ON LAKE ERIE - LAKE ONTARIO NAVIGATION

D-38 With the assumption established that the practical capacity

of the existing Welland Canal would be reached in 1990-1995 under

conditions represented by input traffic demand, tests were made

using the queuing model to determine the impact of selected struc-

tural improvements on transit time and capacity. Alternatives tested

were: (1) a structurally improved Welland Canal featuring four locks

plus a guard lock each with 1200' x 110' dimension, (2) the existing

Welland Canal with the addition of a four-lock (1200 x 110') canal

between Lake Erie and Lake Ontario via the Niagara River (heretofore

referred to as the Niagara Canal), (3) a five-lock Niagara Canal and

(4) a six-lock Niagara Canal.

D-39 **The Structurally Improved Welland Canal**

A Monte Carlo simulation was made using a range of locking times

for a structurally improved Welland Canal assuming a 4-lock (1200 x

110') in series configuration. Figure D-6 shows the results of the

simulation for lock cycle times ranging from 72 to 96 minutes.

These results stress the remarkable sensitivity of system

capacity; however, the resultant loss of maneuverability affecting

a more cautious and slower lock approach leads to a decrease in

system capacity. The average transit times for the Welland Canal

simulation alternative (Figure D-6) suggest that even with the
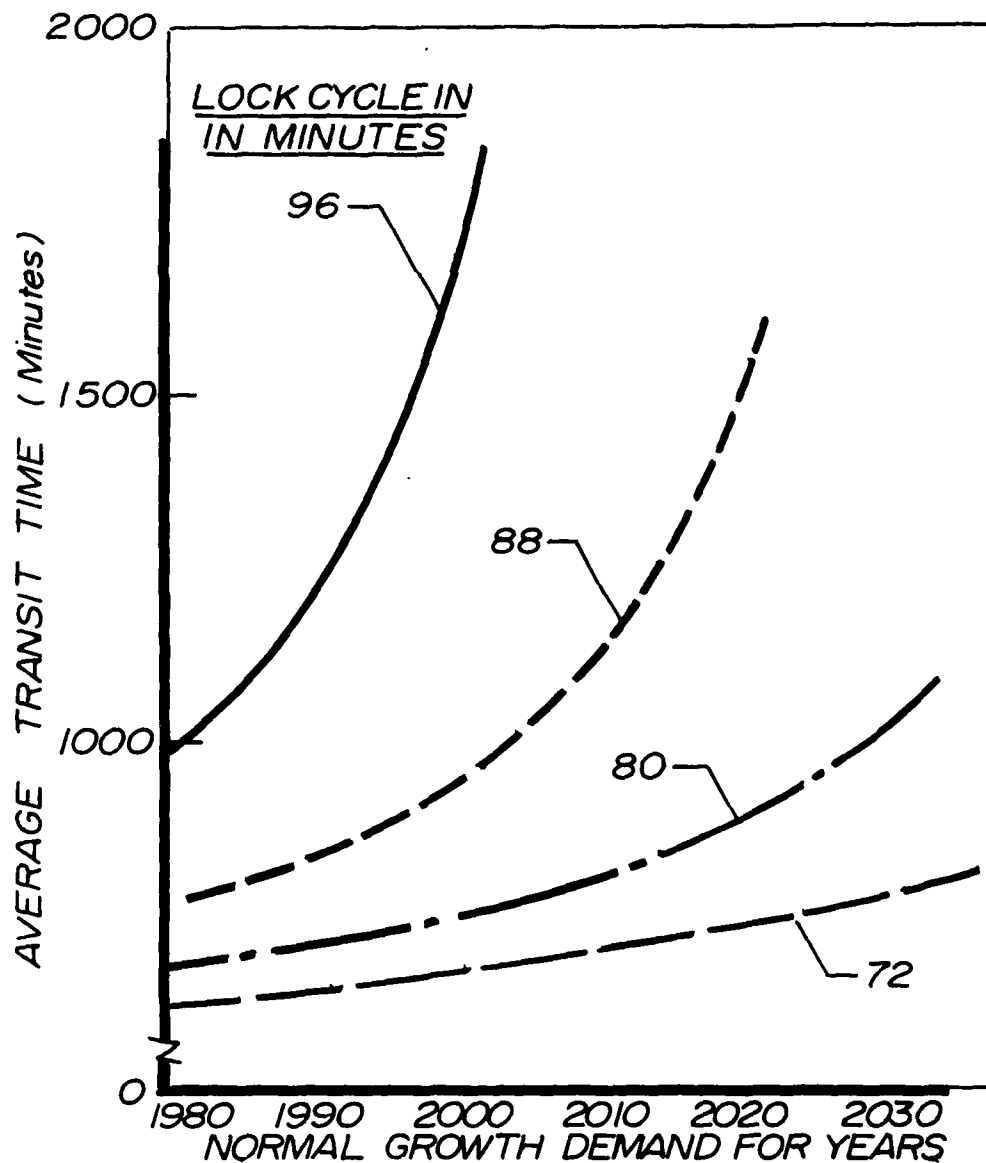
Figure D-6   Transit Performance for the Structurally
Improved Welland Canal

revised system elements including the elimination of one or more locks and replacement with larger locks, transit times for locks continue to approach 1000 minutes for all but the 72 minute lock cycle.

D-40 The Niagara Canal

Three configurations were simulated in these studies. All _on-figurations had the Welland Canal in common, but the Niagara Canal consisted of either four, five, or six locks in series. Passing .s not permitted in any of the reaches except the end reaches of the Niagara Canal which form the outliers of the lakes. Vessels originate at ports and arrive at channel assignment decision nodes where NETSIM/SHIP's channel assignment mechanism is set in motion to determine the channel offering the least expected transit time.

The simulation experiments subjected each network to the same increasing transport demand (Table D-36)from 1980 through to 2030, if necessary in five year increments up to year 2000 and in ten year increments thereafter. Each simulation was examined for signs of saturation to determine if the next higher level of demand experiment was necessary.

D-41 Results of Simulation

Performance statistics from simulations of the twin-canal networks suggested that any of the four-, five-, or six-lock Niagara Canal in combination with Welland would perform equally well under projected traffic up to year 2030. Simulation results for the Welland Five-Lock Niagara Canal are representative of the findings. The imput data for the Welland Five Lock Network are presented in Table D-3€ which

illustrates the traffic level, Table D-44 which presents the corres-
ponding vessel transits and Table D-39 which is a summary of the lock
operation data. As stated earlier there is no definable reason to
expect a differentiation of locking times between the Welland and
Niagara systems other than for the added time required to service
large vessels in an alternative where the Niagara locks are larger
than those of the Welland which would result in a slightly higher
average transit time for the Niagara.

The average simulated system transit times for the Welland-
Five-Lock Niagara Network are compared with the non-structurally
improved Welland in Figure D-41 The comparison of all major alter-
natives is shown in Figure D-42 which includes simulated conditions
for the (1) existing Welland, (2) the non-structurally improved
Welland, (3) the Welland 4-Lock Canal and (4) the Welland 5-Lock
Niagara Network in which the existing Welland is paralleled by the
Niagara Canal.

The results of the Monte Carlo simulations suggest that any one
of the twin-canal configurations would function adequately in meeting
transport demand up to and including that for 2030. Although the
Welland Four Lock Niagara network seemed to offer lower transit times
than the others, no absolute statistical difference between the per-
formances could be established. Therefore, the desirability of a parti-
cular configuration must rest on other engineering and economic criteria
such as initial capital outlay and operating and maintenance expenditures.

Vessel Transits - Welland Canal
1970 Actual, 1980-2030 Projected
Excelerated Growth Conditions

Month		1970	1980	1990	2000	2010	2020	2030
April	Total	535	576	623	683	749	832	927
	Up	315	339	367	402	441	490	546
	Down	220	237	256	281	308	342	381
May	Total	920	991	1,074	1,178	1,293	1,439	1,604
	Up	441	475	515	565	620	690	769
	Down	479	516	559	613	673	749	835
June	Total	799	861	932	1,022	1,121	1,247	1,389
	Up	405	436	472	518	568	632	704
	Down	394	425	460	504	553	615	685
July	Total	842	907	982	1,077	1,182	1,315	1,466
	Up	425	458	496	544	597	664	740
	Down	417	449	486	533	585	651	726
August	Total	831	896	971	1,065	1,169	1,300	1,449
	Up	408	440	477	523	574	638	711
	Down	423	456	494	542	595	662	738
September	Total	851	917	994	1,091	1,197	1,331	1,483
	Up	430	463	502	551	605	673	750
	Down	421	454	492	540	592	658	733
October	Total	904	974	1,055	1,157	1,269	1,412	1,574
	Up	462	498	539	591	648	721	804
	Down	442	476	516	566	621	691	770
November	Total	863	930	1,007	1,104	1,211	1,347	1,502
	Up	418	450	487	534	586	652	727
	Down	445	480	520	570	625	695	775
December	Total	456	491	531	582	638	709	790
	Up	187	201	217	238	261	290	323
	Down	269	290	314	344	377	419	467
Yearly	Total	7,001	7,543	8,169	8,959	9,829	10,932	11,923
	Up	3,491	3,760	4,072	4,466	4,900	5,450	5,944
	Down	3,510	3,783	4,097	4,493	4,929	5,482	5,979
Avg. Daily		25.5	27.4	29.7	32.6	35.7	39.8	43.3
Avg. Monthly		777.9	838.1	907.7	995.4	1,092.1	1,214.7	1,324.8
Avg. Vessel Tonnage/Transit		8,980	10,340	11,500	12,150	12,600	12,800	13,000

FIGURE D-7

Comparison of System Transit Times for

Lake Erie-Lake Ontario Navigation Alternatives

Nonstructurally Improved Welland Canal

Delay Reduction Benefits

5-Lock Niagara/Existing Welland Network

Average Transit Time (minutes)

1800

1600

1400

1200

1000

800

600

1970   1980   1990   2000   2010   2020   2030   2040

Year

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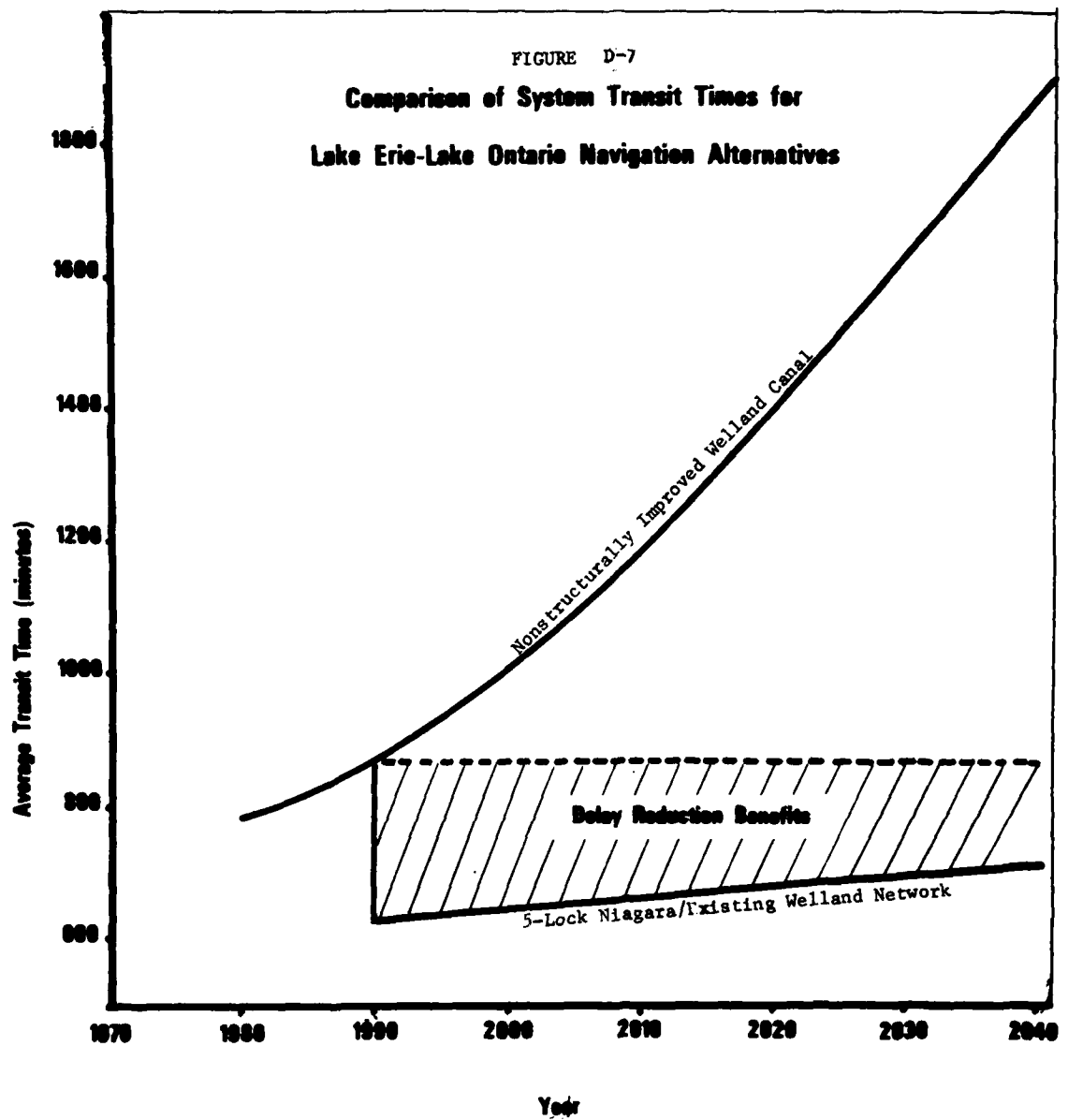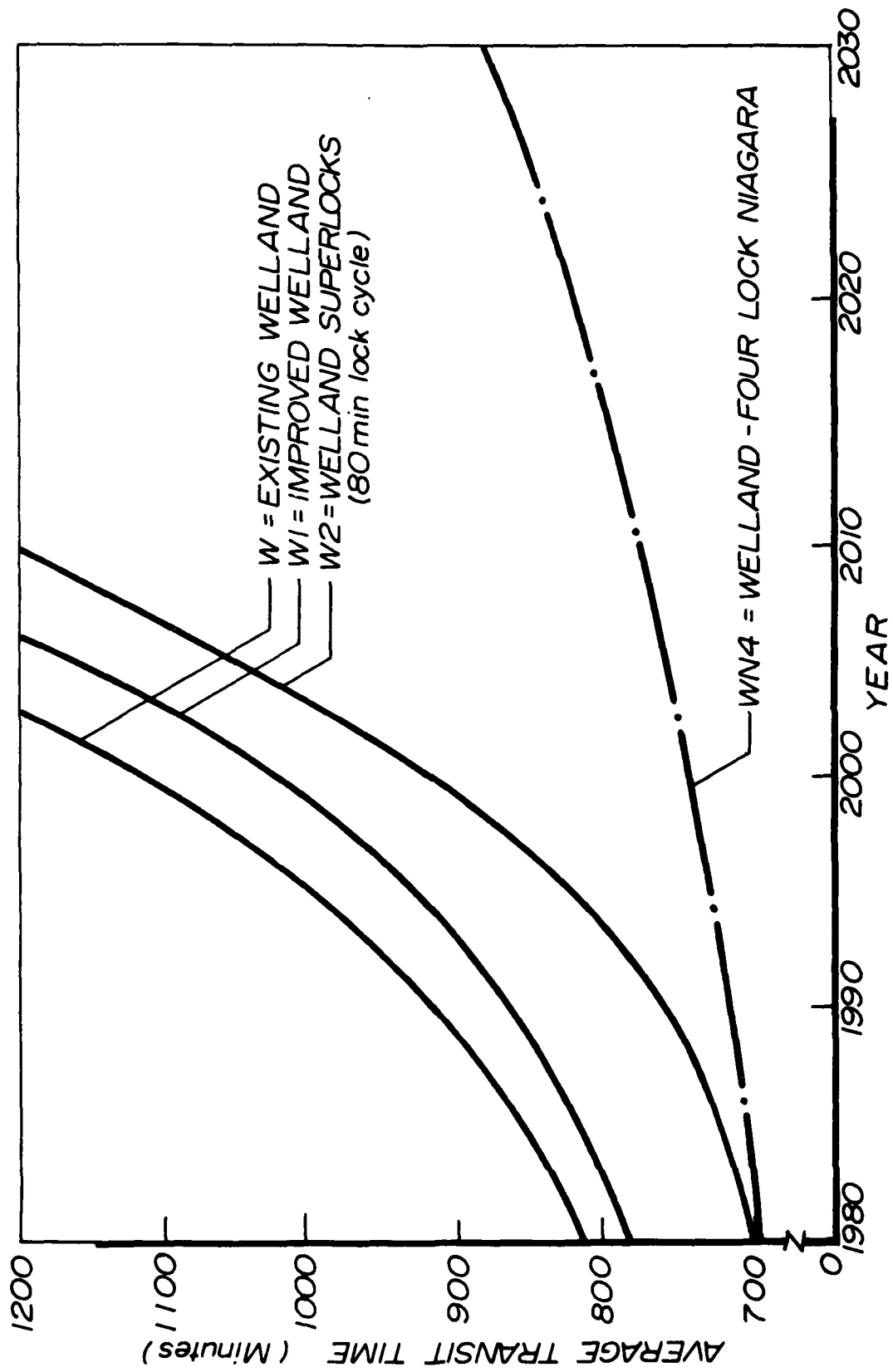
Figure D-8 Transit Summary under Accelerated Growth

The chart legend reads:

W = EXISTING WELLAND
W1 = IMPROVED WELLAND
W2 = WELLAND SUPERLOCKS
(80 min lock cycle)

WN4 = WELLAND - FOUR LOCK NIAGARA

Y-axis: AVERAGE TRANSIT TIME (Minutes)

X-axis: YEAR

The simulation results for the Welland-Niagara 5-Lock Network
for the 1990 decade are listed in Table D-45.   The conclusion is
reached that whereas the alternative tested for the Welland, i.e.,
no improvement, non-structural improvement, and 4-lock replacement,
provided little decrease in transit time (or increase in capacity)
the combination represented in the twin canal alternative provides
major relief in the form of reduction in average transit times.

Table D-45   Summary Statistics for Welland Five Lock

Niagara Subsystem under 1990 Traffic Conditions

1. Vessel Journeys Completed During Simulation   483
2. Total Transit Time (System)   315,115 min.
3. Average Transit Time (System)   652 min.
4. Number of Class I vessels through Welland   64
5. Number of Class II vessels through Welland   193
6. Average Welland Transit Time   637 min.
7. Number of Niagara Journeys   226
8. Average Niagara Transit Time   670 min.
9. Average Niagara Canal Delay   55 min.
10. Total Niagara Canal Delay   12,427 min.
11. Average Niagara Lock Utilization   32.2%
12. Maximum Niagara Lock Delay   138 min.
13. Total Niagara Transit Time   151,352 min.
14. Total Welland Transit Time   163,763 min.

Notes: The simulation run was conducted under the assumption that the
        transit time through the Niagara Canal would be the same as
        that through the Welland Canal for similar circumstances. This
        assumption was implemented by i) using a 72 minute lock cycle
        for the Niagara locks; and ii) scaling down Niagara reach
        transit times to a total of 7 hours and 15 minutes. Average
        arrival rate was 29.7 vessels/day and the fleet composition
        assumed a 16.4:74.5:9.1 proportion of Class I, II and III ves-
        sels.

9 Compared with 920 assuming no improvements and 875 with non-structural
  improvements.

CONCLUSIONS

D-42 The following points summarize the conclusions from the individual simulations:

(1) Under each of three assumptions regarding a single Welland Canal facility with 4 or 7 locks in series of 1200' x 110' and 860' x 80' dimensions, respectively, practical capacity in terms of number of transits per day accommodated was reached in the 1990-2030 period.

(2) Performance statistics from simulations of the twin-canal networks suggested that any of the four-, five-, or six-lock Niagara Canal in combination with Welland would perform equally well under projected traffic through the year 2030. This conclusion must be tempered by the following observations:

i. All twin-canal simulations used a single set of locking data. Under these conditions, no statistical differences could be established between any of the three configurations. Changes in locking data among the various networks could revise this result.

ii. In connection with the above and specifically with regard to the alternative Niagara Canal configurations, the traffic was dominated by Class III vessels; an average lock processing time of 40 minutes was used. This representative time may be compared with the following parameters:

	Identification	Dimension	Average Lift	Average Time Per Lockage
Welland Canal	existing locks	860' x 80'	43'-48'	36 minutes
	with nonstructural improvements	860' x 80'	43'-48'	35 min. (expected)
	super locks	1200' x 110'	80'	40 min. (expected)
	Eisenhower-Snell	860' x 80'	38'-49'	37 min. (for large vessels)

    iii.   The simulation runs assumed a uniform and smooth operation in the channels (reaches) connecting the locks. No channel delays were incorporated into the model. This is not a grave problem for the twin-canal studies since the systems were never in serious congestion. At higher utilization rates, however, major channel delays could "deregulate" vessel interarrival patterns leading to larger delays.

    iv.   The study assumed a SOQA (Serve Opposing Queues Alternately) rule and further included a service lookahead feature so that no "unnecessary" ship delays occurred.

(3)   Given the locking data for the Niagara Canal, immediate benefits of a twin-channel relative to the calibration run (viz., the existing Welland) were manifested in the form of reduced delays and increased capacity together with a reduction in average canal transit time (see Table D-45 and Figure D-7).

(4)   The term nominal capacity refers to the maximum theoretical capacity and is determined by the maximum number of vessels that can be locked through in any time period. The occurrence of random arrivals, however, imposes an increasing delay cost as the system approaches

nominal capacity. Thus, what is needed is a practical capacity which takes into account this delay function. The definition of practical capacity is to a certain extent arbitrary and is truly a function of a number of factors, each of which may be different for various individuals in various systems under various circumstances. For the purposes of this study, practical capacity was defined as that point when the system reaches 75 percent of its nominal capacity.

(5) Nominal capacity of the existing Welland was shown to be 40 lockages per day. Practical capacity as defined above was reached as early as 1990.

(6) Nonstructural improvements in the Welland Canal leading to a reduction in lock cycle increased the economic capacity of the system by less than one decade.

(7) For the Welland Super Locks subsystem a set of canal transit curves for varying lock service rates was developed. The capacity of this system was found to be extremely sensitive to lock service times with less than two decades of capacity added before the 75 percent of nominal capacity is reached.

(8) All the studies assumed the absence of tandem and multiple lockages. Although these currently constitute only 10-15 percent of the total in the Welland Canal, the relaxation of this assumption could lead to higher lock utilizations than those predicted in the studies.

(9) The summary conclusion is reached that although nonstructural
improvements to the existing Welland Canal add significant
capacity in the order of 5 to 10 years, the major solution to
expected traffic delays between Lake Erie and Lake Ontario at
or about 1990 is in the form of parallel facilities either in
the form of an alternate canal or in the twinning of existing
facilities, (by adding an additional larger lock at each ex-
isting locksite) either of which would be expected to provide
adequate future capacity through the year 2040.

EVALUATION

D-43 Any evaluation of the individual studies and their results as
described above must a priori recognize the limitations and assumptions
of the studies. The intent of the following presentation is to make
the reader aware of these limiting factors so that he may assess the
quality and correctness of the studies.

A primary limitation of the study is that it ignores the inter-
action between system congestion and transport demand. To overcome this
limitation, it would be necessary to chart the sensitivity of individual
commodity traffic to system performance, in effect forming a feedback
loop structure that allows a study of the economics of alternative
facilities. Lacking this overall evaluation model, an expected level
of transport demand was used for each year of future forecast.

The simulations performed in this study are nondynamic in the sense that the nature of system interaction as programmed into the existing models is not time-dependent. For example, the simulation model does not forecast the future status of the system. Future conditions may be simulated only by forecasting the future values of the simulation inputs, as was done for this study.

A third limitation concerns the precision of results. Given that the main objective of the study was to establish system performance for alternative levels of transport demand, and given the constraints of time and resources available, no further attempt to estimate precise delay values was made. Intermediate simulation results or other means of replication are required to obtain statistically sound delay estimates[10]. Treating these simulation results as precise numerical values is tantamount to ignoring the stochastic features of both the models and the system.

Finally, the simulation results are conditional upon the accuracy of traffic forecast. Transport demand for future years were prepared by NCD under the assumption that both average vessel size and frequency of trips would gradually increase. While this procedure is certainly reasonable, a different assumption or different growth rates would undoubtedly produce different results.

Within the limitations discussed above and in light of the conclusions from the individual subsystem studies, the following evaluation may be expounded.

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[10] Note that the simulation methodology provides for a permanent record so that simulations need not be duplicated.

The most clear-cut result of these studies is that twin-canal configurations are able to provide better service over a longer period of time than the single Welland configurations. The Welland-Niagara subsystems distinctly reflect excess capacity through the end of the current millennium. The benefits in terms of reduced delays and the absence of congestion may have been understated, however, if there exists a potential for significant improvements in lock cycle times.

The single Welland studies provide testimony to the volatile relationship between system capacity and the lock cycles. While the structurally improved Welland (the Welland Super Locks subsystem) affords some relief in the long run under the assumptions of the analysis, it too merits further attention by way of 1) effect of enlarged lock dimensions on trip frequencies and 2) the potential improvement in transit-time through traffic control. Neither of these parameters could be explicitly incorporated into the models and must be either qualitatively assessed or expressed in terms of efficiencies in model input data.

ATTACHMENT D-1

DETERMINATION OF EXPECTED TRANSIT TIME (ETT) EQUATIONS

ATTACHMENT D-1

DETERMINATION OF EXPECTED TRANSIT
TIME (ETT) EQUATIONS

TABLE OF CONTENTS

TABLES

INTRODUCTION

In the Welland-Niagara studies, where the configuration consists of parallel channels, a channel choice decision rule becomes necessary to distribute traffic between the two branches. The rule will make an unconditional assignment of those ships whose size prohibits them from using one of the channels, otherwise, channel assignment will be made on the basis of least expected transit time. When a vessel arrives at the channel choice point, the simulation model invokes the expected transit time (ETT) equations to execute this rule. The derivation of the ETT equations for the Niagara Canal is accomplished through the "Experience Data Base" (EDB) technique.

Essentially, the EDB procedure involves separating a multichannel system into distinct single channels. Each channel is then simulated individually to determine its unique operating characteristics under various assumptions about traffic levels and traffic composition, and about alternative service facilities and operating rules within the branches. Once a set of observations of channel performance have been recorded, regression analysis is used to relate conditions at the time vessels entered the channel to their subsequent transit times.

The EDB procedure is not used to develop the ETT equation for the Welland Canal, however, because the elaborate control system that currently exists at Welland augers numerous difficulties for simulation. Empirical data is available in the form of daily vessel records and these were obtained from the St. Lawrence Seaway Authority.

A

WELLAND CANAL ETT EQUATIONS

Welland Canal transit data for the month of August, 1971 was used as the basis for this analysis. The format of this data as originally supplied for downstream travel is shown in Table A. Data for upstream travel was provided in similar format. Preliminary data treatment consisted of transforming this data into a transit time matrix as shown in Table D. This matrix was then subjected to regression analysis with vessel transit time as the dependent variable.

For purposes of regression, it was found necessary to model Welland in the most detailed manner possible. To illustrate, on the macro side, Welland could simply be modeled as one entity, and the independent variables in Table B could only consist of two rows, viz., the number of downbound vessels in the canal and the number of upbound vessels in the canal. Such a model was attempted but the degree of predictability in the resultant regression equation was extremely small. On the micro side, Welland could be modeled as the set of locks, reaches and bridges as it currently exists, and the independent variables could consist of the number of upbound and downbound vessels in each reach and at each upbound and downbound queues of locks and bridges. The data requisite for this model was not available, however. The most detailed model that could be established consisted of a six entity (reach) representation of Welland with the first and last reaches being the two waiting areas at either ends of the canal. This model is schematically portrayed in Figure D-3, page D-84

The conventional linear model was used in the form:

$$TR_j = a + b_1 S_{1j} + b_2 S_{2j} + \ldots + b_i S_{ij} + U_j$$

B

TABLE A . REPRESENTATIVE WELLAND TRANSIT DATA DAILY RECORDS

** V E S S E L   T R A N S I T   A N A L Y S I S **

PERIOD ANALYSED : 71/08/01/0001 TO 71/08/31/2359   DOWNBOUND   AUG 01 TO AUG 31 1971   09/17/71

AGT	PC #	VESSEL NAME	CL	LNG	BM	GROSS TONS	MEAN DRAFT	TIME OF CALL-IN	OUTSIDE DOCK	WAIT	DOCK	LOCK1	LOCK7	BRG10	BRG18	LOCK10	TRANSIT	WAIT+ TRANS
A12	7712	CANOPUS	O	619	75	16400	2507	08/21/1110		6 02		6 23	47	2 28	1 18		10 56	16 58
211	7744	NORSE CAPTAIN	O	555	70	14724	2511	08/21/1215		5 47		6 45	1 42	1 56	1 31		11 54	17 41
769	0718	PIC RIVER	I	383	45	3569	1904	08/21/1300	4 00	2 30		6 56	3 02	1 44	1 11		12 53	15 23
181	1346	CAROL LAKE	I	715	75	15265	2404	08/21/1328		7 59		7 32	1 36	2 01	1 59		12 08	20 07
416	0898	PAUL H TOWNSEND	I	446	50	4302	2201	08/21/1646		6 14		6 27	2 42	1 45	49		11 43	17 57
609	65..	PAUL LORENZ RUSS	O	448	63	4475	1800	08/21/2300		5 31		5 33	1 23	1 42	52		9 30	15 01

INLAND	11					8610			41	3 32		6 22	34	1 49	1 04		10 49	14 21
OCEAN	9					8292			11	5 00	1 07	6 10	27	1 50	1 16		10 43	13 43
08/21	20	DOWNBOUND		AVE GT		8469	TOT GT	169388	28	4 12	30	6 17	31	1 50	1 09		10 46	14 58

A33	1350	JOHN A FRANCE	I	723	75	15874	2510	08/22/0030		1 13		5 41	2 22	1 52	1 13		11 08	12 21
304	5060	KELTEMI	O	461	61	7286	2508	08/22/0155	1 36	2 28		5 35	59	1 52	50		9 16	11 44
069	5471	UINOS M	O	468	62	7962	1832	08/22/0510		1 32		5 34	1 20	1 54	1 12		10 00	11 32
A33	0657	JOHN E F MISENER	I	654	68	12029	2411	08/22/0512		2 22		6 14	1 14	2 01	1 48		11 17	13 39
418	5586	URANUS	O	349	49	2460	1604	08/22/0548		5 49		7 21	1 20	1 57	51		11 23	17 18
127	1765	TADOUSSAC	I	730	75	17948	2509	08/22/0735		2 27		7 55	40	2 08	1 06		11 49	17 18
935	1717	CANADIAN CENTURY	I	730	75	18179	2508	08/22/0842		4 01		5 44	2 26	1 47	1 19		11 16	14 17
935	0770	H BRUCE ANGUS	I	620	68	10760	2308	08/22/0903		5 02		5 51	1 34	2 03	1 20		12 48	17 50
127	0548	STADACONA	I	664	67	11279	2403	08/22/1105		5 23		7 31	21	2 05	56		12 53	18 08
409	7650	CAPO SAN MARCO	O	440	59	4999	1505	08/22/1913		3 40		3 48	2 48	1 45	1 07		7 28	11 08
492	1159	BUCKEYE MONITOR	I	550	58	7377	2011	08/22/1949		3 20		4 57	57	3 13	1 22		10 29	13 49
535	7064	HERMOSA	O	543	69	10217	2510	08/22/1950		4 50		5 08	58	2 30	1 39		10 15	15 05
127	0517	FORT YORK	I	462	56	5915	1510	08/22/2231		3 22		4 31	1 17	2 17	1 49		9 54	13 16

INLAND	8					12820			20	3 24		6 18	1 36	2 11	1 22		11 27	14 51
OCEAN	5					6724			08	3 40		5 29	1 05	2 00	08		9 42	13 21
08/22	13	DOWNROUND		AVE GT		10229	TOT GT	132985		3 30		5 59	1 24	2 06	16		10 46	14 16

954	0908	AVONDALE	I	489	52	4939	1700	08/23/0001		2 02		4 31	1 29	2 02	2 35		10 37	12 39
935	1453	NORTHERN VENTURE CDN	I	730	75	15182	1508	08/23/0025		4 16		5 10	1 10	2 14	1 02		9 34	13 52
254	5122	GLOXINIA	O	460	60	7665	2511	08/23/0610		2 00		4 41	1 14	2 05	1 02		9 02	11 02
127	1400	GUFTICO	I	730	75	16777	2529	08/23/1040		1 08		5 18	39	2 05	63		9 05	10 13
954	1021	WESTDALE	I	569	56	6437	1907	08/23/1042	1 18	2 02		4 25	41	1 47	49		7 42	9 42
713	0824	PATERSON	I	574	59	7857	2001	08/23/1105	2 14	2 41		4 45	13	1 37	38		8 38	12 19
179	7491	LAWRENTIAN	I	576	75	14007	2510	08/23/1325		1 19		5 52	1 23	1 59	59		10 13	11 32
389	1763	INDUSTRIAL TRANSPORT	I	391	55	4902	2209	08/23/1335		3 30		5 54	45	1 52	48		9 19	12 49
179	7276	PACIFIC SKOU	I	613	75	15761	2509	08/23/1540		4 42		5 29	1 17	1 46	57		9 29	14 11
781	7595	MATIJA GUBEC	O	461	67	9333	2510	08/23/1520		4 17		5 16	1 55	1 33	42		9 33	13 50
486	7737	ACTIVITY	O	447	56	4884	1405	08/23/1921		2 12		4 01	1 50	1 34	34		9 07	11 19
418	7661	MAKDINA HEEFER	O	342	47	2269	1930	08/23/1934		2 24		6 04	1 25	1 43	48		9 44	11 10
181	0015	MENIREK LAKE	I	715	75	15150	2409	08/23/2030		2 27		7 03	48	2 05	56		10 52	13 19
127	0525	HOCHELAGA	I	640	67	12068	2307	08/23/2033		3 19		7 13	35	2 16	1 00		11 04	13 23
916	6707	KING MINOS	O	524	65	11157	1530	08/23/2321		2 04		7 21	1 04	1 42	49		10 56	13 00

Source: St. Lawrence Seaway Authority

TABLE B   TRANSIT TIME MATRIX FOR ETT ANALYSIS

System conditions and parameters for each vessel at time of channel choice / Vessel Identification Numbers	Vessel 1	Vessel 2	Vessel 3	. . .	Vessel N
# upbound vessels in reach from Lock 1 to Lock 7					
# downbound vessels in reach from Lock 1 to Lock 8					
# upbound vessels in reach from Lock 7 to Bridge 10					
# downbound vessels in reach from Lock 7 to Bridge 10					
# upbound vessels in reach from Bridge 10 to Bridge 18					
# downbound vessels in reach from bridge 10 to Bridge 18					
# upbound vessels in reach from Bridge 18 to Lock 8					
# downbound vessels in reach from Bridge 18 to Lock 8					
# upbound vessels in downstream waiting area					
# downbound vessels in upstream waiting area					
# upbound vessels in dock inside canal					
# downbound vessels in dock inside canal					

D

where TR_j and S_{ij} represent the observed transit time and system conditions for vessel j. The symbol U_j represents a random disturbance term. The basic S_{ij} variables are shown in the first column of Table C These were not the only variables, however, since power and logarithmic transforma- ·tions were also made.

The final results of the regression procedure are shown in Table D. Table E provides a description of the variables present in the equation. The fraction of explained variance, R^2, was much higher when the dependent variable, total transit time (TR), did not include the waiting time (see Table A, second to last column). Inclusion of waiting time in the dependent variable increased the degree of unpredictability. This may be due to certain features of the existing control system at Welland, features such as vessels called out of the waiting area for tandem lockages, vessel delays due to adverse weather conditions, change of pilot, inspections and other aspects of regulated traffic.

NIAGARA CANAL ETT EQUATIONS

EDB simulation runs were executed for four, five and six lock con- figurations with fleet data generated from 1980, 2000 and 2030 normal growth projections. The output from each run was again transformed into a transit time matrix such as that shown in Table C The matrices for each configuration were merged so as to cover the widest possible range of sys- tem conditions and were subjected to regression analysis. The regression models for these Niagara configurations were more detailed than that for Welland, in that the independent variables representing system conditions included not only the reach variables (number of vessels by direction of

E

TABLE C   WELLAND ETT EQUATION (in hours)

(1) UPSTREAM

DEPENDENT VARIABLE: Total transit time through Welland (including wait)

FRACTION OF EXPLAINED VARIANCE: .46733

| VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LAGNEW	0.376432D 00	0.411421D-01	0.3765927	0.4143
ND_2	0.383365D 00	0.131997D 00	0.1086059	0.1430
SD_3	0.754415D-01	0.427205D-01	0.0644761	0.0875
SD_4	0.926512D-01	0.464242D-01	0.0741416	0.0988
LU_1	0.225923D 00	0.153781D 00	0.0541829	0.0729
LU_W	-0.454765D 00	0.225390D 00	-0.2108705	-0.0999
RU_W	0.256836D 01	0.491750D 00	0.5661076	0.2515
RD_1	-0.324908D 00	0.211833E 00	-0.0573008	-0.0761
LENGTH	0.233132D-02	0.689477D-03	0.1249778	0.1659

INTERCEPT 0.426149D 01

F

TABLE C   Continued

(ii) DOWNSTREAM

DEPENDENT VARIABLE: Total transit time through Welland (including wait)

FRACTION OF EXPLAINED VARIANCE: .55335

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LAGNEW	0.476575D 00	0.365000D-01	0.4777967	0.5378
ND_4	0.385893D 00	0.119657D 00	0.1111952	0.1556
SU_1	0.184415D-01	0.111713D-01	0.1009804	0.0804
LD_6	-0.389481D 00	0.171599D 00	-0.2016935	-0.1102
RU_1	-0.855268D 00	0.321271D 00	-0.1610076	-0.1290
RD_6	0.208184D 01	0.361084D 00	0.2315529	0.2711
LENGTH	0.367386D-02	0.501665D-03	0.2437868	0.3369

INTERCEPT 0.337656D 01

G

TABLE D WELLAND ETT VARIABLES
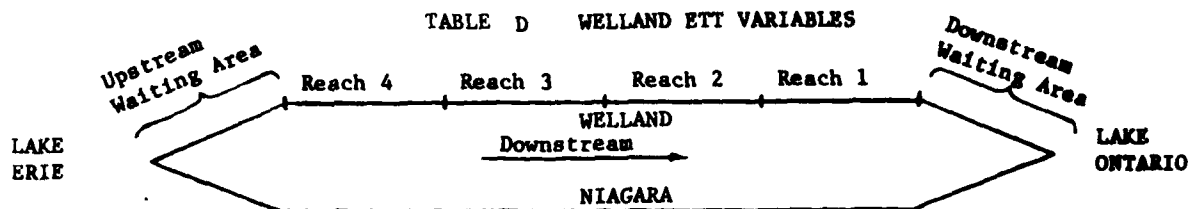
Reach 1 extends from Lock 1 to Lock 7
Reach 2 extends from Lock 7 to Bridge 10
Reach 3 extends from Bridge 10 to Bridge 18
Reach 4 extends from Bridge 18 to Lock 8

Length: vessel length in feet

Lagnew: transit time of the previous vessel

ND_4: number of ships downbound in reach 4

ND_2: number of ships downbound in reach 2

RU_6: square root of number of ships upbound in upstream waiting are

RD_6: square root of number of ships downbound in downstream waiting area

RU_1: square root of number of ships upbound in reach 1

RD_1: square root of number of ships downbound in reach 1

SD_3: square of number of ships downbound in reach 3

SD_4: square of number of ships downbound in reach 4

SU_1: square of number of ships upbound in reach 1

LD_6: $\log_{10}$ of number of ships downbound in downstream waiting area

LU_1: $\log_{10}$ of number of ships upbound in reach 1

LU_6: $\log_{10}$ of number of ships upbound in upstream waiting area

H

travel) but also the lock variables consisting of the upstream and downstream queue sizes at each individual lock.

The Niagara Canal ETT equations are shown in Tables E, F and G for the four, five and six lock configurations respectively. An interpretation of the variables is given in Table H along with schematic diagrams of the relative locations of locks and reaches for each configuration. In general, the equations conform to prior expectations that the transit time of a vessel would be most sensitive to the density of traffic at the nearest lock.

I

TABLE E   FOUR-LOCK NIAGARA ETT EQUATION (in minutes)

(1) UPSTREAM
DEPENDENT VARIABLE: Total Transit Time
FRACTION OF EXPLAINED VARIANCE: 0.97799

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LNQ_1	0.128062D 03	0.147069D 01	0.9216316	0.9708
LNQ_2	0.739400D 02	0.174264D 02	0.0388975	0.1935
LFQ_3	0.505910D 02	0.114121D 02	0.0422043	0.2018
LNQ_4	0.972029D 02	0.138766D 02	0.0551865	0.3096
RSD_1	0.651215D 02	0.229557D 02	0.0217239	0.1307
RSD_2	0.785285D 02	0.350833D 02	0.0158691	0.1035
ROD_2	0.112642D 03	0.321609D 02	0.0243930	0.1607
ROD_3	0.519045D 02	0.209395D 02	0.0203515	0.1144
RSD_5	0.477330D 02	0.159498D 02	0.0215911	0.1378
ROD_5	0.683644D 02	0.176575D 02	0.0294533	0.1771
RSD_6	0.295962D 02	0.114527D 02	0.0181829	0.1192
ROD_6	-0.375666D 02	0.121825D 02	-0.0260663	-0.1419
RSD_7	0.179670D 02	0.488548D 01	0.0311048	0.1685
LENGTH	0.137982D 00	0.576509D-01	0.0166323	0.1105

INTERCEPT 0.673420D 03

J

TABLE E   Continued

(11) DOWNSTREAM

DEPENDENT VARIABLE: Total Transit Time through Niagara Canal

FRACTION OF EXPLAINED VARIANCE: 0.99289

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LNQ_1	0.944880D 01	0.108216D 01	0.0810104	0.3821
LFQ_2	0.885795D 02	0.662832D 01	0.0619293	0.5347
LNQ_3	0.479479D 02	0.946324D 01	0.0291004	0.2333
LFQ_3	0.646476D 02	0.542014D 01	0.0650312	0.4918
LNQ_4	0.111899D 02	0.692778D 01	0.0078434	0.0763
LFQ_4	0.117500D 03	0.106588D 01	0.8338810	0.9821
RSD_2	0.295368D 02	0.173315D 02	0.0068259	0.0786
ROD_4	0.422856D 02	0.127239D 02	0.0150137	0.1555
RSD_5	0.362803D 02	0.794833D 01	0.0206128	0.2113
ROD_5	0.190467D 02	0.877641D 01	0.0099133	0.1022
RSD_6	0.112175D 03	0.817861D 01	0.0579338	0.5447
ROD_6	-0.141864D 02	0.638055D 01	-0.0119520	-0.1047
RSD_7	0.116941D 03	0.247979D 01	0.2291548	0.9127
ROD_7	-0.163148D 02	0.484939D 01	-0.0177069	-0.1573
LENGTH	0.962425D-01	0.313661D-01	0.0126310	0.1438

INTERCEPT 0.652511D 03

K

TABLE F FIVE-LOCK NIAGARA ETT EQUATION (in minutes)

(1) UPSTREAM

DEPENDENT VARIABLE: Total Transit Time through Niagara Canal

FRACTION OF EXPLAINED VARIANCE: 0.98590

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LNQ_1	0.131287D 03	0.154000D 01	0.9715041	0.9876
LFQ_1	0.102128D 03	0.304933D 02	0.0370941	0.2397
LNQ_2	0.107556D 03	0.211650D 02	0.0584050	0.3508
LNQ_3	0.432919D 02	0.241377D 02	0.0177532	0.1311
LFQ_3	-0.595863D 02	0.244310D 02	-0.0261788	-0.1770
ROD_1	0.917735D 02	0.204792D 02	0.0399188	0.3137
RSD_2	0.113509D 03	0.361449D 02	0.0296027	0.2255
ROD_2	0.101136D 03	0.351438D 02	0.0257448	0.2075
RSD_3	0.170004D 03	0.267730D 02	0.0696860	0.4240
RSD_7	0.272912D 02	0.124687D 02	0.0195770	0.1593
LENGTH	0.107553D 00	0.593917D-01	0.0161236	0.1323

INTERCEPT 0.101814D 04

L

TABLE F   Continued

(ii) DOWNSTREAM

DEPENDENT VARIABLE: Total Transit Time through Niagara Canal

FRACTION OF EXPLAINED VARIANCE: 0.99609

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LNQ_1	0.426694D 01	0.101592D 01	0.0457397	0.3026
LFQ_2	0.898127D 02	0.119224D 02	0.0675740	0.4948
LNQ_3	0.807327D 02	0.141759D 02	0.0481134	0.3954
LFQ_4	0.630556D 02	0.571296D 01	0.0944388	0.6406
LNQ_5	0.592524D 02	0.799089D 01	0.0469071	0.4889
LFQ_5	0.121777D 03	0.118158D 01	0.8073556	0.9919
ROD_2	0.199838D 02	0.120264D 02	0.0083154	0.1246
RSD_4	0.841145D 02	0.118064D 02	0.0503562	0.4742
ROD_4	0.993720D 02	0.138965D 02	0.0581006	0.4755
RSD_6	0.409592D 02	0.802495D 01	0.0308260	0.3600
ROD_6	C.388190D 02	0.103696D 02	0.0210043	0.2723
RSD_7	0.112125D 03	0.801061D 01	0.0741707	0.7268
RSD_8	0.123381D 03	0.265781D 01	0.3091608	0.9611
ROD_8	0.967826D 01	0.411984D 01	0.0153297	0.1748
LENGTH	0.627421D-01	0.250447D-01	0.0124431	0.1861

INTERCEPT 0.748405D 03

M

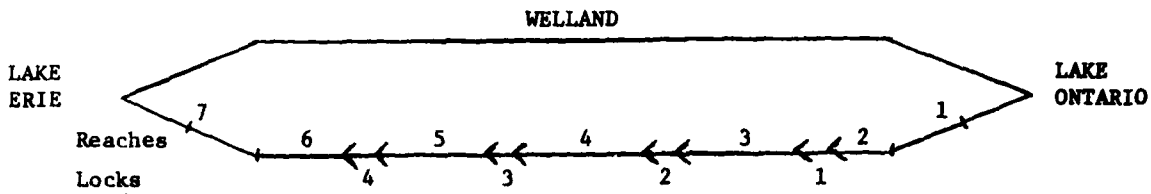TABLE G   SIX-LOCK NIAGARA ETT EQUATION (in minutes)

(1) UPSTREAM

DEPENDENT VARIABLE: Total Transit Time through Niagara Canal

FRACTION OF EXPLAINED VARIANCE: 0.96375

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LNQ_1	0.115567D 03	0.202687D 02	0.5001696	0.8023
LNQ_6	-0.845838D 02	0.299256D 02	-0.1650713	-0.5544
LFQ_6	0.336228D 02	0.2019000 02	0.1960829	0.3654
RSD_1	0.185674D 03	0.331979D 02	0.2852926	0.7957
RSD_2	0.239012D 03	0.569587D 02	0.2227606	0.7032
ROD_2	-0.146597D 03	0.906919D 02	-0.0818607	-0.3560
RSD_7	0.904977D 02	0.439171D 02	0.1274145	0.4369
ROD_8	0.847158D 02	0.195474D 02	0.2215236	0.7145
RSD_9	0.605419D 02	0.202067D 02	0.2194666	0.5769
ROD_9	0.500531D 02	0.904412D 01	0.3026941	0.7936

INTERCEPT 0.941233D 03

N·

TABLE G   Continued

(ii) DOWNSTREAM

DEPENDENT VARIABLE: Total Transit Time through Niagara Canal
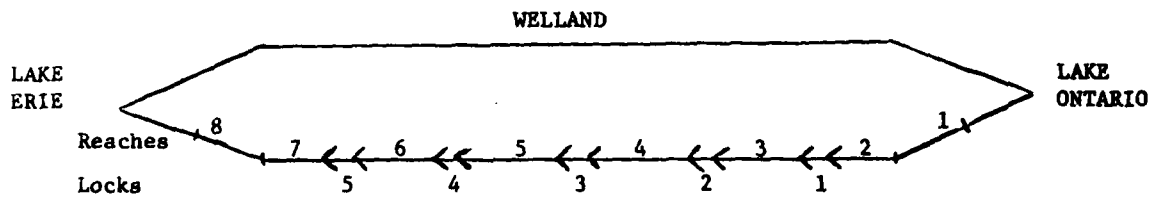
FRACTION OF EXPLAINED VARIANCE: 0.86970

VARIABLE	REGRESSION COEFFICIENT	STAND. DEVIATION FOR COEFFICIENT	STAND. REGRESSION COEFFICIENT	PARTIAL CORRELATION COEFFICIENT
LFQ_1	-0.263485D 03	0.197382D 02	-1.2177836	-0.9121
LNQ_2	0.698844D 03	0.145431D 03	0.3417007	0.6251
LFQ_6	0.686898D 03	0.158272D 03	0.3750146	0.5861
RSD_1	-0.206870D 03	0.109104D 03	-0.1341303	-0.3013
ROD_1	-0.696366D 03	0.163901D 03	-0.3025588	-0.5779
RSD_2	-0.691331D 03	0.163259D 03	-0.2846443	-0.5766
ROD_5	-0.436546D 03	0.244021D 03	-0.1235550	-0.2857
RSD_9	0.308975D 03	0.772103D 02	0.3130363	0.5549
ROD_9	0.950879D 02	0.299316D 02	0.2310617	0.4679

INTERCEPT 0.121421D 04

0

TABLE H NIAGARA ETT VARIABLES

WELLAND

LAKE
ERIE

Reaches 7 6 5 4 3 2 1

Locks 4 3 2 1

LAKE
ONTARIO

(i) Four-lock configuration (with seven reaches)

WELLAND

LAKE
ERIE

Reaches 8 7 6 5 4 3 2 1

Locks 5 4 3 2 1

LAKE
ONTARIO

(ii) Five-lock configuration (with eight reaches)

WELLAND

LAKE
ERIE

Reaches 9 8 7 6 5 4 3 2 1

Locks 6 5 4 3 2 1

LAKE
ONTARIO
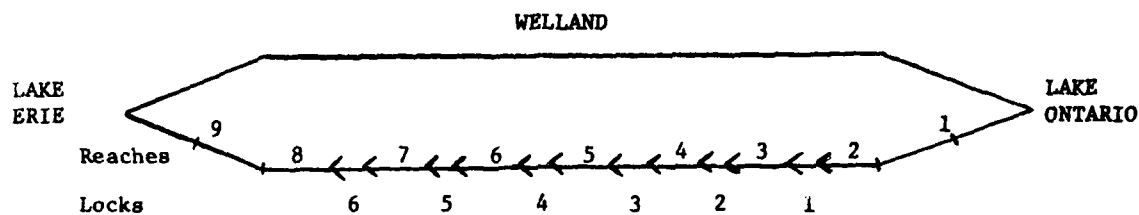
(iii) Six-lock configuration (with nine reaches)

LNQ_i = number of vessels in near[1] queue at lock i

LFQ_i = number of vessels in far queue at Lock i

RSD_j = number of vessels travelling same direction[2] in Reach j

ROD_j = number of vessels travelling opposite direction in Reach j

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[1] in relation to the subject vessel

[2] in relation to the subject vessel's direction of travel

P

ATTACHMENT D-2

DESCRIPTION OF THE QUEUING MODEL

USED IN THE SINGLE WELLAND STUDIES

The queuing model used to supplement the Single Welland Simulation Studies (see Section IV) is a simple waiting-line model, mathematically categorized as M/G/1. That is, arrivals into the service facility are assumed to be Poisson distributed, there is only one service facility and the service times for the arrival units are independent with some common probability distribution whose mean $1/\mu$ and variance σ^2 are known.

The terminology used below is as follows:

λ = mean arrival rate (expected number of arrivals per minute)

μ = mean service rate (expected number of units completing service per minute)

σ^2 = variance of the service distribution

$\rho = \lambda/\mu$ = traffic intensity

W = waiting time in queue in minutes

Under the assumptions given above, the Pollaczek-Khintchine formula establishes the waiting time[1] as:

$$W = \frac{\lambda^2 \sigma^2 + \rho^2}{2\lambda(1-\rho)}$$

In the context of this analytical model, the Welland Canal is viewed as one entity--a single service facility. Arrival units incur delays in waiting areas at either ends outside the Welland Canal and the transit time through the canal itself is fairly constant. This approach was formulated on the basis of the empirical data as given below. The transit time distribution through the Welland Canal has a very small variance while the delay distributions have large variances.

Although a state-dependent function for Welland Canal transit time was obtained through regression (i.e., the transit time through the canal

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[1]Note: when the service distribution is exponential, so that $\sigma^2 = 1/\mu^2$, then the above equation reduces to the M/M/1 case with $W = \dfrac{\lambda}{\mu(\mu - \lambda)}$

A

| Transit Time Distribution	Upstream Waiting Area	Welland Canal	Downstream Waiting Area
Mean (min.)	151.00	615.00	149.00
Standard Deviation (min.)	122.00	131.00	102.00
St. Dev. as % of the Mean	80.79%	21.30%	68.45%

Source: VESSEL TRANSIT ANALYSIS, St. Lawrence Seaway Authority.

was expressed as a function of the system conditions), the major contribution to the magnitude of transit time was the intercept term with other variables providing for minor fluctuations indicating again that once a ship enters the canal, its actual transit time is almost constant.

The primary objective of this effort then became the prediction of delays in waiting areas outside the canal. The rate at which the canal could absorb the arrival flows and dissipate queues needed to be identified. This rate, or more accurately this service distribution was determined through analysis of the VESSEL TRANSIT ANALYSIS daily reports for the months of June and August.

The traffic flows for these months are shown in Figure C.8. Weekly patterns may be readily seen, although there are enough variations to make accurate prediction difficult. Average flows were 25.1 and 24.7 per day discounting multiple lockages.[2] Since the number of daily arrivals vary greatly from day to day, the delay times for these units were associated with the traffic density into the canal during the 24 hours preceding an arrival.

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[2] Approximately 11% of the arrival units were assumed to undergo multiple lockages.

B
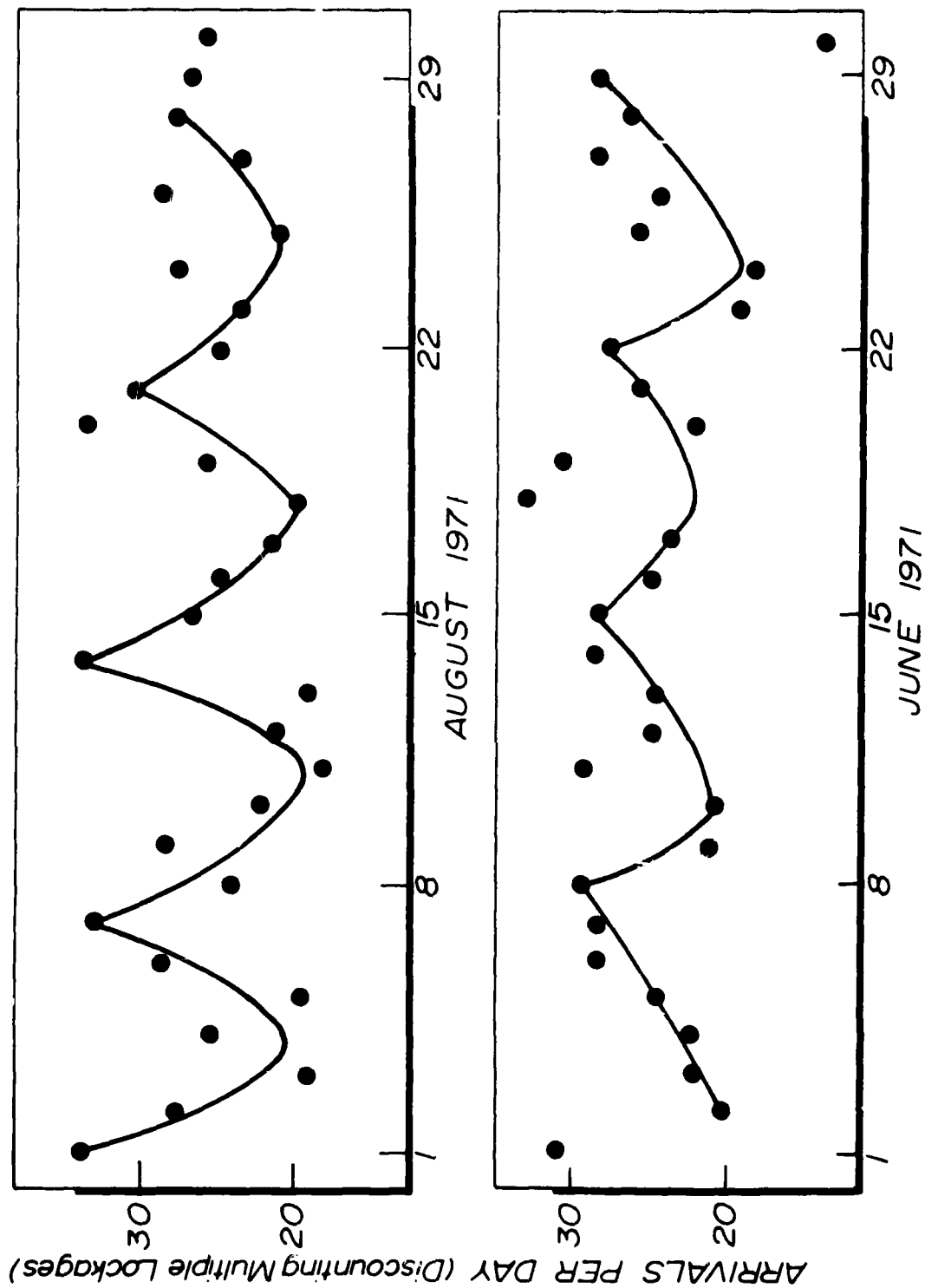
Source: VESSEL TRANSIT ANALYSIS, St. Lawrence Seaway Authority

Figure A   Traffic Flows at the Welland Canal

The results from this analysis are shown in Figure D-10. The service distribution finally obtained is described in terms of an average service cycle[3], μ equal to .0112 min^{-1} (1/μ ~90 min.) and a standard deviation, σ equal to .0288 min^{-1}. The waiting time characterized by these parameters corresponds well with empirical data over a wide range of traffic.

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[3]A service cycle is the time to process two vessels from opposite directions consecutively.
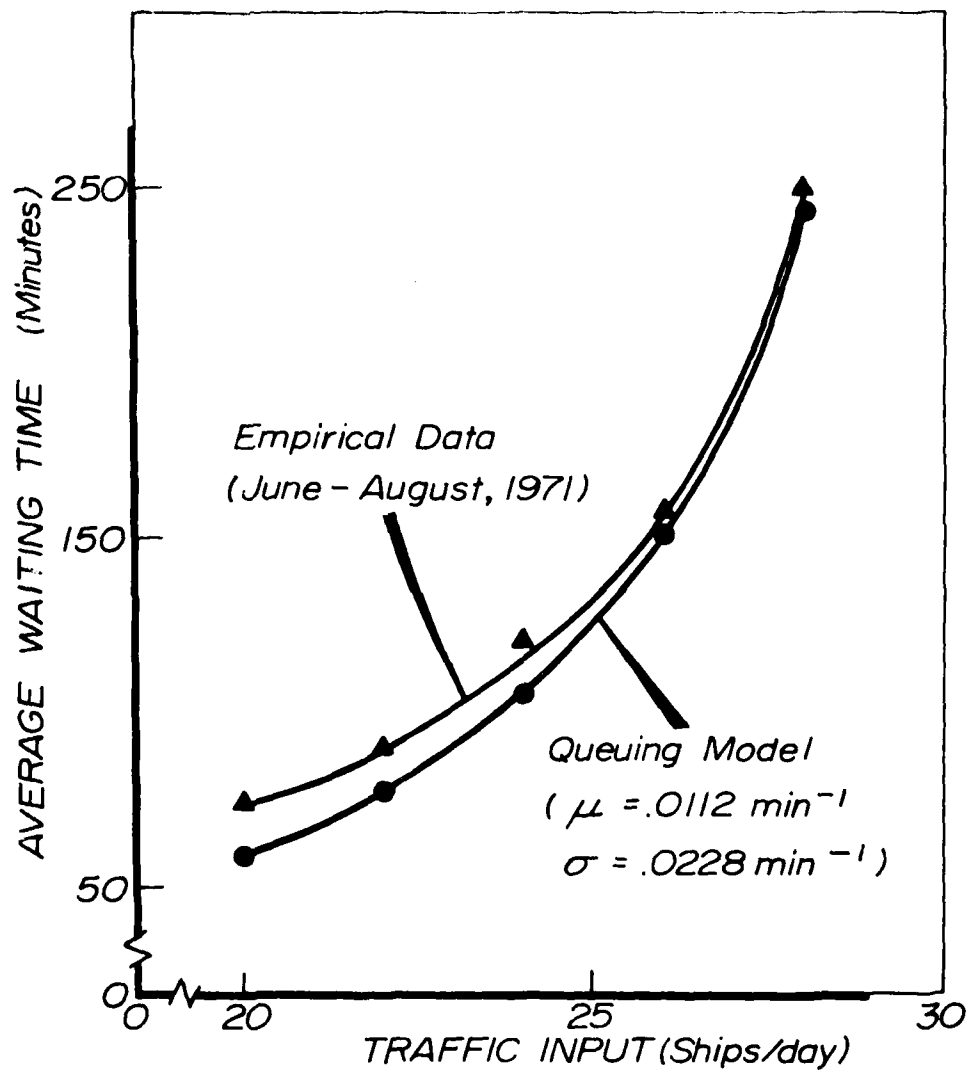
Figure **B**   Comparison of Analytical Results with Empirical Data

E

ATTACHMENT D - 3

CONTACTS MADE REGARDING
RATE ANALYSIS

Steamship Lines and Agents Contacted Regarding Rate Analysis

American Export Lines, Inc., Chicago, Ill.
American Mail Line, Park Ridge, Ill.
American President Lines, Ltd., Chicago, Ill.
Anchor Shipping Co., Chicago, Ill.
Associated Great Lakes Freight Conferences, Chicago, Ill.
Atlantic Shipping Company, Chicago, Ill.
Columbus Line, Chicago, Ill.
Continental Shipping Agency, Ltd., Chicago, Ill.
Dart Container Line, Chicago, Ill.
Delta Steamship Lines, Inc., Chicago, Ill.
Eckert Overseas Agency, Chicago, Ill.
Farrell Lines, Inc., Chicago, Ill.
Furness Withy Agencies, Chicago, Ill.
General Steamship Agencies, Inc., Milwaukee, Wis.
Great Lakes Overseas, Inc., Chicago, Ill.
Great Lakes Overseas, Inc., Cleveland, Ohio
Intercontinental Container & Transport Co., Rosemont, Ill.
International Great Lakes Shipping Company, Chicago, Ill.
International Great Lakes Shipping Company, Cleveland, Ohio
International Great Lakes Shipping Company, Toledo, Ohio
International Great Lakes Shipping Company, Milwaukee, Wis.
Inter Ship Inc., Chicago, Ill.
Jan Uiterwyk Co., Chicago, Ill.
Kerr Steamship Company, Chicago, Ill.
Keuker Steamship Services, Inc., Chicago, Ill.
Lykes Brothers Steamship Co., Inc., Chicago, Ill.
Mardell Shipping Company, Detroit, Mich.
Midwestern Shipping Agencies, Inc., Chicago, Ill.
Mitsui OSK Lines Ltd., Chicago, Ill.
Nauticus Shipping Corporation, Chicago, Ill.
Navicom, Inc., Milwaukee, Wis.
Nordship Agencies, Inc., Chicago, Ill.
Nordship Agencies, Inc., Cleveland, Ohio
Nordship Agencies, Inc., Milwaukee, Wis.
Norton Lilly & Company, Chicago, Ill.
Norton Lilly & Company, Cleveland, Ohio
Overseas Steamship Agencies, Inc., Dearborn, Mich.
Patton Steamship Agency, Inc., Detroit, Mich.
Patton Steamship Agency, Inc., Toledo, Ohio
Protos Shipping, Inc., Chicago, Ill.
Prudential Grace Lines, Arlington Heights, Ill.
Sea Train International, Arlington Heights, Ill.
States Marine Lines, Inc., Des Plaines, Ill.
Strachan Shipping Company, Chicago, Ill.
Texas Transport Company, Chicago, Ill.
Tri Coast Shipping Company, Chicago, Ill.
U. S. Lines, Oak Brook, Ill.
U. S. Navigation Co., Inc., Chicago, Ill.
U. S. Navigation Co., Inc., Cleveland, Ohio
World Shipping, Inc., Cleveland, Ohio
Zim American Israeli Shipping Co., Inc., Chicago, Ill.

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*Exceptional cooperation was provided by U. S. Navigation Co., Chicago, Ill.

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Port Authorities and Representatives Contacted Regarding Rate Analysis

Ameriport - Ports of Philadelphia, Chicago, Ill.

Board of Harbor Commissioners, Milwaukee, Wis.

Cleveland Cuyahoga County Port Authority, Cleveland, Ohio

Detroit-Wayne County Port Commission, Detroit, Mich.

New Orleans Board of Commissioners, Chicago, Ill.

Port of Los Angeles, Los Angeles, Calif.

Port of New York Authority, Chicago, Ill.

Port of Portland, South Holland, Ill.

Port of San Francisco, Chicago, Ill.

Port of Seattle, Chicago, Ill.

Seaport of Chicago, Chicago, Ill.

Seaway Port Authority of Duluth, Duluth, Minn.

State of Ill. Dept. of Business and Economic Development, Chicago, Ill.

State of Mich. Dept. of State Highway Transportation Planning, Lansing, Ill.

Toledo-Lucas County Port Authority, Toledo, Ohio

Virginia Port Authority, Chicago, Ill.

ATTACHMENT D - 4

SECTION I REFERENCES

SECTION I, TRAFFIC ANALYSIS

References

Aase, James H.; Transportation of Iron Ore, Limestone, and Bituminous Coal on the Great Lakes Waterway System; Bureau of Mines information circular 8461; 1970.

Booz-Allen Applied Research, Inc.; Forecast of U. S. Oceanborne Foreign Trade in Dry Bulk Commodities; Maritime Administration, Department of Commerce, Contract No. MA-4533; 1969.

D. Wm. Carr & Associates Ltd.; The Seaway in Canada's Transportation - An Economic Analysis, Volume 2, Seaway Potential in Competition and Traffic; St. Lawrence Seaway Authority; 1970.

EBS Management Consultants; An Economic Analysis of Improvement Alternatives to the St. Lawrence Seaway System; U. S. Department of Transportation, Contract No. DOT-05-A8-018; 1969.

Economic Evaluation Group; Interim Report, Extension of the Navigation Season: Evaluation of Canadian Costs and Benefits; St. Lawrence Seaway Authority; 1972.

Gibb, Alberry, Pullerits, and Dickson; Future Port Requirements-Western Lake Ontario; Department of Public Works of Canada; 1969.

Institute for Water Resources; U. S. Deepwater Port Study-Commodity Studies and Projections; Corps of Engineers, IWR Report 72-8; 1972.

International Great Lakes Levels Board; Regulation of Great Lakes Water Levels, Appendix E, Navigation; International Joint Commission; 1973.

J. Kates and Associates; St. Lawrence Seaway Tolls and Traffic-Analysis and Recommendations; St. Lawrence Seaway Authority; 1965.

Stanford Research Institute; Economic Analysis of St. Lawrence Seaway Cargo Movements and Forecasts of Future Cargo Tonnage; U. S. Department of Commerce, Contract No. C-194-65; 1965.

U. S. Bureau of the Census; Domestic and International Transportation of U. S. Foreign Trade: 1970; U. S. Government Printing Office, Washington, D. C., 1972.

SECTION I, TRAFFIC ANALYSIS
References Continued

U. S. Army Engineer Division, Lower Mississippi Valley; Waterborne
     Commerce in the United States, Part 3, Waterways and Harbors,
     Great Lakes; Corps of Engineers; 1970, 1971.

U. S. Army Engineer Division, North Central; Grain Traffic Analysis to
     Accompany Great Lakes Harbors Study; Corps of Engineers,
     Chicago; 1965.

U. S. Army Engineer Division, North Central; Great Lakes Harbors Study;
     Corps of Engineers, Chicago; 1966.

U. S. Army Engineer Division, North Central; Great Lakes Overseas
     General Cargo Traffic Analysis,to accompany Great Lakes Harbors
     Study; Corps of Engineers, Chicago; 1967.

U. S. Army Engineer Division, North Central; Origin-Destination Study
     of Bulk Commodity Movement-Upper Great Lakes Region; Corps of
     Engineers, under cooperative agreement with Upper Great Lakes
     Regional Commission, Chicago; 1972.

U. S. Army Engineer Division, North Central; Stone Traffic Analysis to
     Accompany Great Lakes Harbors Study; Corps of Engineers,
     Chicago; 1958.

U. S. Water Resource Council; OBERS Projections-Economic Activity in
     the United States; Volume 1, Concepts, Methodology, and
     Summary Data; U. S. Government Printing Office, Stock No.
     5245-0012; 1972.

Waller, Roger M. and Allen, William B.; Geology and Groundwater Conditions,
     Appendix No. 3 to Great Lakes Basin Framework Study; United States
     Geological Survey of Great Lakes Basin Commission, Ann Arbor; 1970.

St. Lawrence Seaway Authority and the St. Lawrence Seaway Development
     Corporation; Traffic Report of the St. Lawrence Seaway, 1972;
     Office of Communications, Seaway Circle, Massena, N.Y.; 1973.

ATTACHMENT D − 5

SECTION II REFERENCES

SECTION II, TRANSPORTATION RATE ANALYSIS

References

Aase, James H. Transportation of Iron Ore, Limestone, and Bituminous Coal on the Great Lakes Waterway System, BuMines Information Circular 8461, 1970.

American Iron and Steel Institute, Annual Statistical Report, 1966 through 1971, New York, N.Y.

Bross, Steward R. Ocean Shipping, Cornell Maritime Press, Cambridge, Maryland, 1956, p. 149.

Draine, Edwin H. Freight Rate Structure, Transportation Division, Chicago Association of Commerce and Industry, January, 1965.

Duluth Board of Trade, Annual Reports, 1960-1971.

Eastern Area Military Traffic Management and Terminal Service, Brooklyn, New York.

EBS Management Consultants Incorporated, An Economic Analysis of Improvement Alternatives to the St. Lawrence Seaway System, U. S. Department of Transportation Contract No. DOT-OS-A8-018, January 1969.

Executive Summary Relationship of Land Transportation Economics to Great Lakes Traffic Volume, U. S. Department of Commerce Maritime Administration, Contract No. 1-35492, October 1971.

Federal Maritime Commission, Bureau of Compliance, Office of Tariffs and Practices.

Grand Trunk Western Railroad Company, Freight Tariff, 239-F.

Great Lakes Basin Framework Study, Appendix No. 9, Volume 1, Commercial Navigation - Draft No. 2, Navigation Work Group - Great Lakes Basin Commission, February 1972.

J. Kates and Associates, St. Lawrence Seaway Tolls and Traffic-Analyses and Recommendations, The St. Lawrence Seaway Authority, December 1965.

Lake Carriers' Association, Annual Report, 1960, 1965 through 1970.

Leeming, Joseph. Modern Ship Stowage, Edward W. Sweetman Company, New York, 1968.

Maritime Research Incorporated, Chartering Annual, 1972, New York.

A

SECTION II, TRANSPORTATION RATE ANALYSIS

References Continued

Oglebay Norton Company, Cleveland, Ohio.

Port of New York, Information No. 16, February 1, 1973, "Railroad
    Ship-A-Train Rates."

Skillings' Mining Review, "Great Lakes Region Ore Shipments in 1971 Season",
    January 22, 1972, p.6.

Skillings' Mining Review, "Rail and Lake Freight Rates on Iron Ore per
    Gross Ton", June 17, 1972, p. 20.

Snavely, King and Tucker, Incorporated. A Study of the Effects of Inland
    Freight Rates and Services on the St. Lawrence Seaway. Washington,
    D. C., December 15, 1971.

Stahlbaum, Captain O. and W. Moth, Stowage Factors for All Kinds of
    Merchandise, Verlag Okis, Hamburg.

Statistics Canada, Transportation and Public Utilities Division,
    Transportation Section Shipping Report, Part V, Origin and
    Destination for Selected Commodities, 1970.

Stanford Research Institute, Economic Analyses of St. Lawrence Seaway
    Cargo Movements and Forecasts of Future Cargo Tonnage, U. S.
    Department of Commerce Contract No. C-194-65(Neg.), November 1965.

Thomas, Captain R. F., revised by Thomas, Captain O. O., Stowage-the
    Properties and Stowage of Cargoes, Brown, Son & Ferguson, Ltd.
    Nautical Publishers, 52 Darnby Street, Glasgow; Sixth Edition, 1968.

Thomas Publishing Company. Thomas Register of Manufacturers. New York,
    1970.

U. S. Army Engineer Division, North Central, Great Lakes Harbors Study,
    Summary Report, November 1966.

U. S. Army Engineer Division, North Central Corps of Engineers, Origin-
    Destination Study of Bulk Commodity Movement Upper Great Lakes
    Region. Under Cooperative Agreement with Upper Great Lakes Regional
    Commission, Chicago, Ill., June, 1972.

U. S. Bureau of the Census, Census of Manufactures: 1967, General Summary
    Subject Report and Selected Area reports MC67(3), U. S. Government
    Printing Office, Washington, D. C., 1970.

References Continued

U. S. Bureau of the Census, Domestic and International Transportation
of U. S. Foreign Trade: 1970, U. S. Government Printing Office,
Washington, D. C., 1972.

U. S. Department of the Army, Corps of Engineers, Grain Traffic Analysis,
June 1965.

U. S. Department of the Army, Corps of Engineers, Waterborne Commerce of
the United States, Part 3, Waterways & Harbors, Great Lakes,
(Annuals 1958 through 1970).

U. S. Department of the Army, Corps of Engineers, Waterborne Commerce of
the United States, Part 5, National Summaries, 1965 through 1970.

U. S. Department of Commerce, Bureau of the Census, Current Industrial
Report, Series MA-161(69)-2, "Survey of the Origin of Exports by
Manufacturing Establishments": 1969-Jan. 7, 1971.

U. S. Bureau of the Census, Foreign Trade Division, Chi go Association
of Commerce & Industry, Research & Statistics Div: on, U. S. Great
Lakes Ports Monthly Statistics for Overseas and C 'ian Waterborne
Traffic.

U. S. Department of Commerce, Maritime Administration, Essential United
States Foreign Trade Routes, Washington, D. C. U. S. Government
Printing Office, December 1969, p. 78.

Upper Great Lakes Regional Commission Transportation as a Factor in the
Future of Lake Superior District Iron Ores by Wilbert G. Fritz,
Washington, D. C., April 1971.

ATTACHMENT D - 6

SECTION III REFERENCES

SECTION III, SIMULATION

REFERENCES

1. Great Lakes Simulation Studies, Volume 1--NETSIM: A General Network Simulator, Report TTSC 7215, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, 1971.

2. "The Traffic Control System for the Welland Canal," Engineering Journal, June 1968.

3. Luce, A. M., and Sandor, P., "A Systems Approach to the Problem of Increasing the Effective Capacity of the Welland Canal," Transportation Research Forum Proceedings, 1965.

4. Rea, John C., and Nowading, David C., Waterway Systems Simulation: Volume V--Simulation of Multiple Channel Deep Draft Navigation Systems. Report TTSC 7112, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, 1971.

5. Desai, Kiran J., "Determination of Steady State Conditions for Waterway Simulation Experiments," Tech. Memo. No. 6, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, June 1972.

6. Rao, Srikanth, "Estimating the Variance of the Sample Mean of Auto-correlated Data in Simulation Experiments," Tech. Memo. No. 7, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, July 1972.

7. Carroll, Joseph L., and Bronzini, Michael S., Analysis of Waterway Systems--Summary Report, Report TTSC 7212, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, 1972.

8. Santina, William J., and Wesler, George B., "Duplicate Locks for Illinois Waterway," Journal of the Waterways and Harbors Division, ASCE, Vol. 90, No. WW4, Proc. Paper 4118, Nov., 1964.

9. Davis, J. P., "Tonnage Capacity of Locks," Journal of the Waterways and Harbors Division, ASCE, Vol. 95, No. WW2, Proc. Paper 6577, May, 1969, pp. 201-213.

10. Ferguson, H. A., Engel, H., and Blok, S.I.E., (Untitled), XXII International Navigation Congress, Paris, 1969, Permanent International Association of Navigation Congresses, Brussels, Belgium, Section 1, Inland Navigation, Subject 4, pp. 97-114.

11. Hayward, John, "Simulation Analysis of a Multiple Chamber Lock on the Inland Waterway," Report TTSC 7211, Pennsylvania Transportation and Traffic Safety Center, The Pennsylvania State University, University Park, Pennsylvania, September 1972.

A